RETURN TO VENUS

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RETURN TO VENUS

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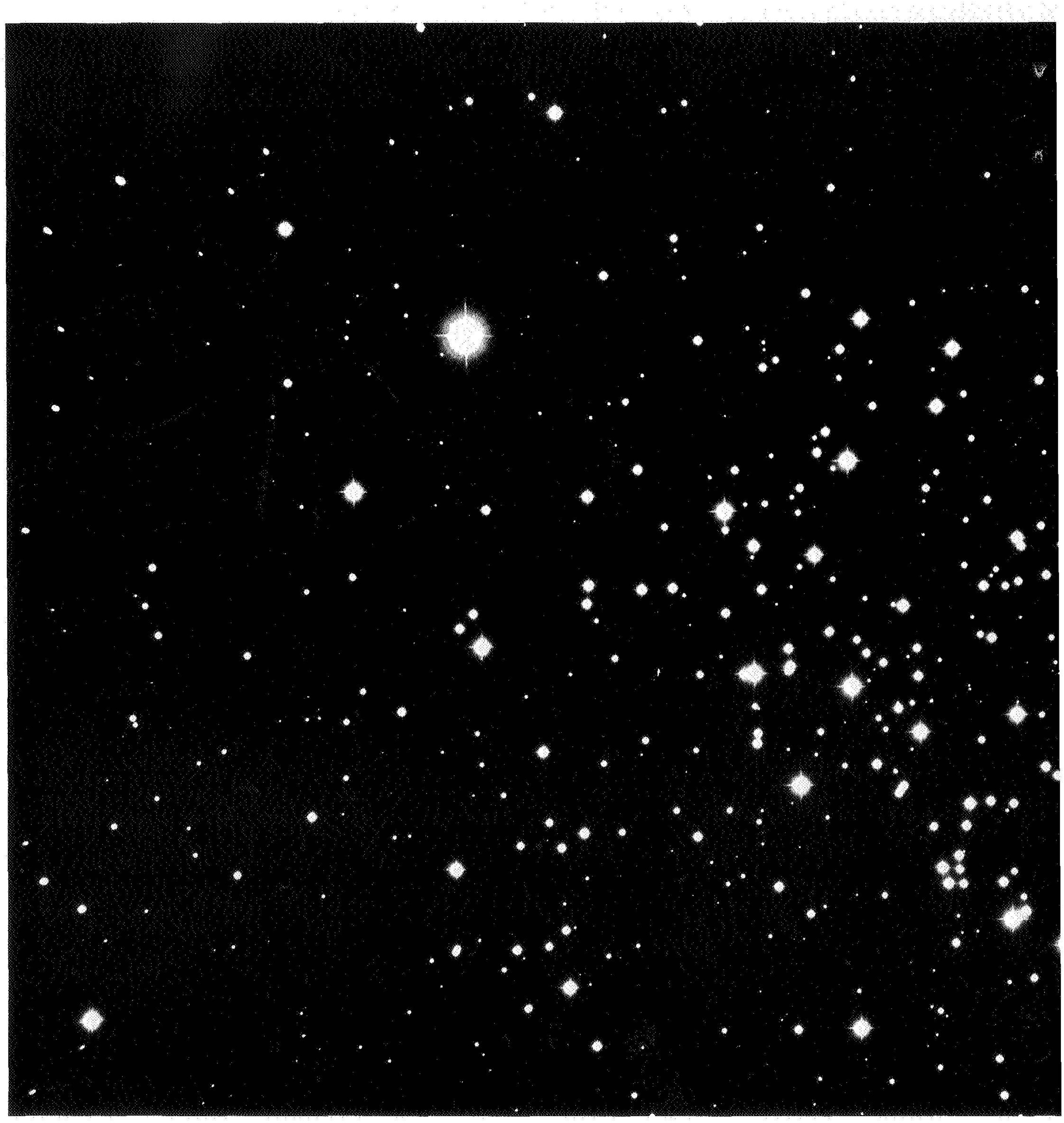
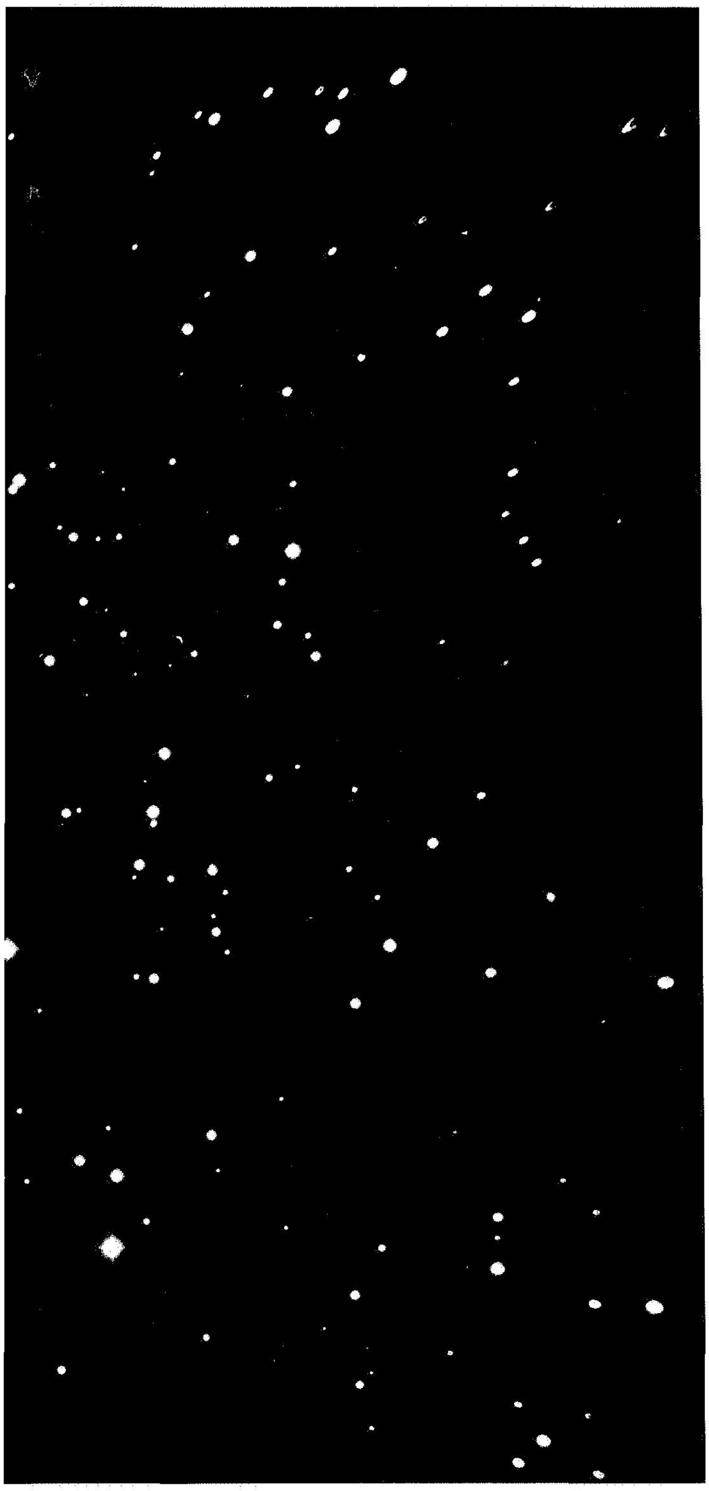


RENDEZVOUS

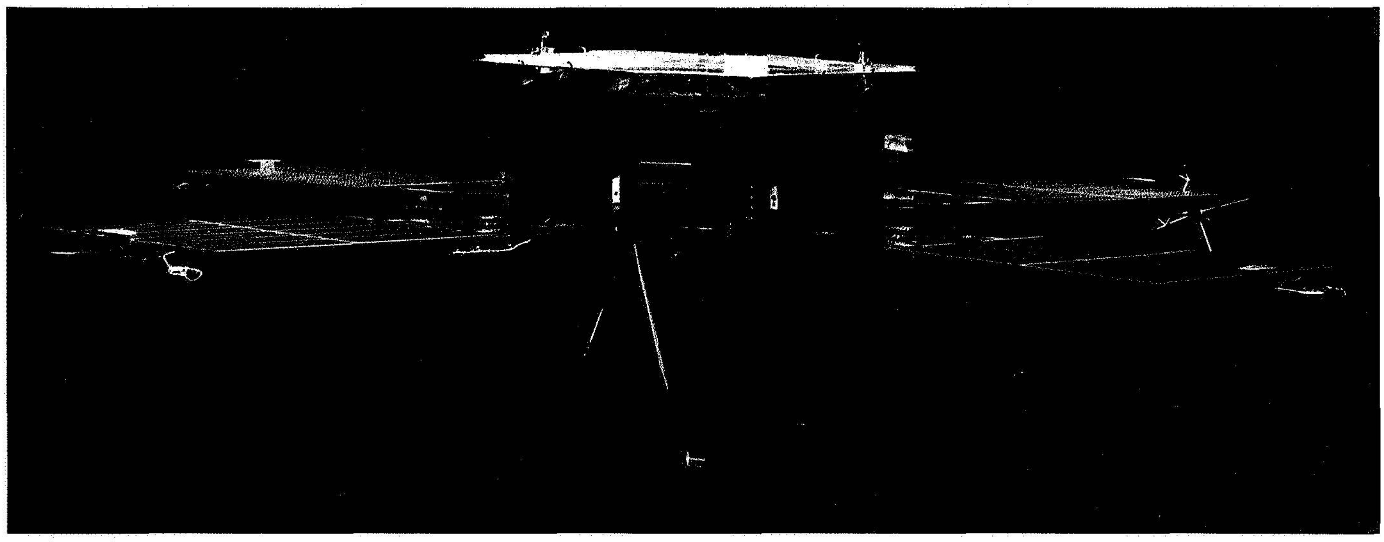


Out in the sparkling dark between planets it could have been any time, any day, any age in the history of the solar system. You could not have told time by watching the stars wheel overhead, for they were fixed in the surrounding sky. Nor could you check the angle of the Sun, for it too was immobile. The only way to tell time would be internally, from the heartbeat: by this reckoning, Mariner V was over three thousand hours out from Earth.

Since the dawn of navigation, sailors have known where they are and how they are going by watching the water, recognizing landmarks, and observing the Sun and stars. The nearest ocean to Mariner V was fifty million miles astern; the nearest land was the hot and clouded planet showing a thin crescent just ahead. The Sun was steady overhead, the stars were all around. Nevertheless, the spacecraft's position and velocity were accurately known, more accurately than those of the target planet, by means of precise radio tracking and careful computation. Doppler tracking techniques which could sense the velocity between spacecraft and Earth-based tracking station to an accuracy of a small fraction of an inch per second, and planetary ranging which could measure the distance within about fifty yards, combined to navigate Mariner V more skilfully than any sailor of the old oceans.

Almost five years before, another Mariner had ventured this way. Mariner II completed the world's first interplanetary flight literally on one wing. One of the two solar panels was partly shorted out, so that the other panel bore the entire electric-power load; the Earth sensor, which kept the spacecraft oriented so that communication with Earth was possible, was near its brightness threshold, and might lose sight of Earth. Some parts of the spacecraft were as much as 100°F hotter than expected, and several temperature sensors were off-scale. The spacecraft computer, which had been the primary source for switching and other commanded events for 109 days, was apparently unable to conduct the encounter functions, which had to be commanded from Earth. Still, Mariner II had made it.

But this time was different. About every five-sixths of a second, Mariner V sent a telemetry measurement to Earth. Until about six hours before encounter, two-thirds of the measurements had been scientific, one-third engineering. And the engineering data, one after



Mariner V as it appears in space (sunlight from top)

another, showed a flawless spacecraft. Each number fell in the expected range. Now, as Mariner and Venus rushed toward each other, all the data were scientific—no need now for routine normal engineering information. All was well.

Let us for a moment view the universe from the perspective of Mariner V. It is a machine designed to sail where man cannot yet go. Its senses are alien, its language foreign to all mankind. Still, let us try.

First, tens of thousands of stars would be visible to our eyes. To Mariner's working eyes, there are only two: the Sun, and, near the south celestial pole, the bright star (magnitude −0.9), Canopus.

We would observe the Sun's diameter to be about a third greater, and its apparent brightness almost doubled, compared to the way it looks from near the Earth, not allowing for atmospheric effects; we would be burned by its heat and blinded by its visible and ultraviolet output. To Mariner, it is a lighthouse, a source of heat and electric power, and an object of study.

The next most prominent object visible in the sky would, of course, be Venus. For weeks, it would have shown a narrowing crescent; now the brightly glowing sliver would rotate over the north and widen to a dazzling gibbous phase as the spacecraft flashes down, ahead, and to the sunward side of Venus. The disk would widen to an angular diameter of nearly seventy-five degrees shortly before the half-lighted phase. To Mariner, almost all of this is meaningless. One of its sensors is designed to detect the planet's edge about an hour before closest approach in order to start the recording of planetary scientific measurements. Another sensor, detecting the night/day terminator as the spacecraft sails across the disk, will trigger the reorientation of the spacecraft's reflector antenna. In addition, the influence of Venus will be felt in the bending of Mariner's flight path and, for about three hours, by four scientific instruments on the spacecraft.

The third brightest object in Mariner's sky at this point, shining blue and bright in the dim constellation of Aquarius, is the world on which we live. Mariner V cannot see it optically, but the green-painted reflector antenna through which the spacecraft speaks its endless monologue of digital telemetry words is pointed at Earth, and almost throughout the encounter, the spacecraft hears three voices from Earth. One of these voices is the tracking and command uplink signal from the Goldstone Deep Space Station in the Southern California desert. The other two are the signals transmitted from an antenna near Stanford University for one of the scientific experiments of the mission.

But for twenty-one minutes, at the spacecraft, these voices fall silent. We would see the faraway bluish spark of Earth dim and die, engulfed by the dark curve of the looming planet Venus, a few minutes after closest approach, and then struggle free of the glare of the sunlit edge a long half hour later.

Finally, as Mariner leaves Venus behind and speeds around and closer to the Sun, we might look out in alarm at an Earth which no longer speaks nor hears, with regret to a Venus shrinking to its normal proportions in a busy sky, and with apprehension toward the swelling Sun.

To Mariner V, so long as the Sun and Canopus retain their ordained positions, so long as there is nitrogen gas in the attitude-control tanks and electric power coming in, all is well. It continues its digital monologue, two-thirds science data and one-third engineering, to a sky which does not include the Earth.

This creature still swims in its true habitat, though far from the shores of its birth. The return of a Mariner to Venus in 1967 is, by comparison with the suspenseful, exciting first flight of five years earlier, almost a natural event.

MARINER

Mariner V was the latest branch of a noble family tree. As its name indicates, it represents the fifth launch of the family: two Venus attempts in 1962 and two Mars launches in 1964 preceded it. In addition, there were two study and design projects in which much of the Mariner character originated. Finally, as Mariner V flew its assigned course, another Mariner effort, destined for a second-generation Mars flight, was in design and development, and future members of the family were being considered.

Mariner began in the plans of the National Aeronautics and Space Administration as the early-stage planetary element of a lunar–planetary related series of projects, keyed to the NASA launch vehicle series, and involving step-by-step development of hardware, techniques, and scientific information with interaction between lunar and planetary projects as well as progress from each project to the next. The execution of these projects was delegated to the Jet Propulsion Laboratory.

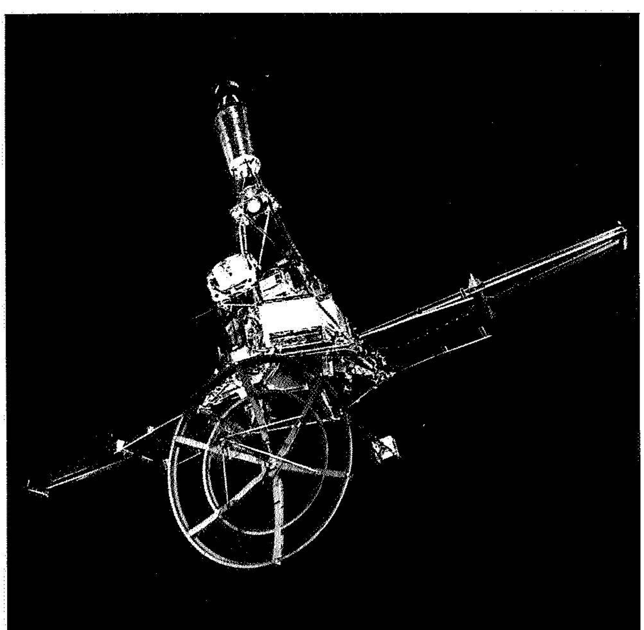
The first flights were to be the Ranger lunar-impact missions, including an early test-flight phase to demonstrate certain spaceflight techniques and designs necessary to both series. Ranger was launched by the Atlas/Agena B vehicle, which was considered somewhat small for planetary missions; the first Mariner design and development efforts were scaled to the larger Atlas/Centaur, which was then being designed to launch more than a ton to the Moon, or slightly less than a ton to Mars or Venus.

Design and development were begun for a Venus mission, called Mariner A, and, a little later, for a Mars mission, called Mariner B. These being the first planetary attempts, a fly-by mission which encounters the target planet briefly in a continuing heliocentric path was chosen in each case.

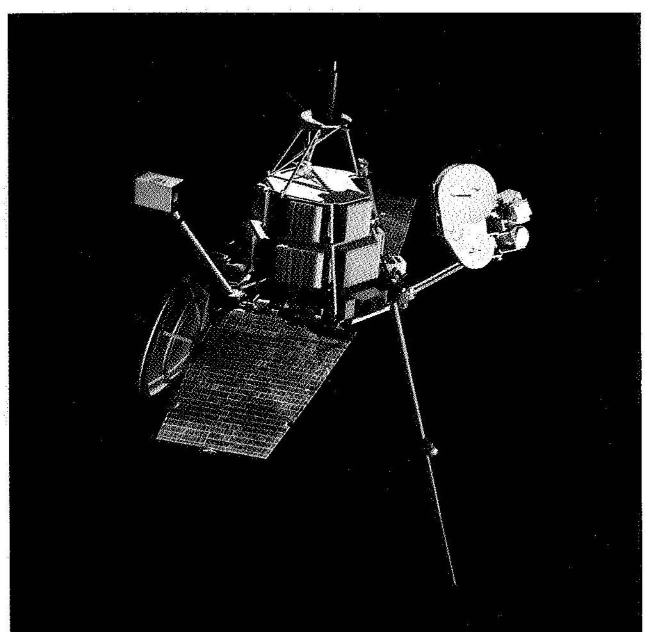
1962: TO VENUS

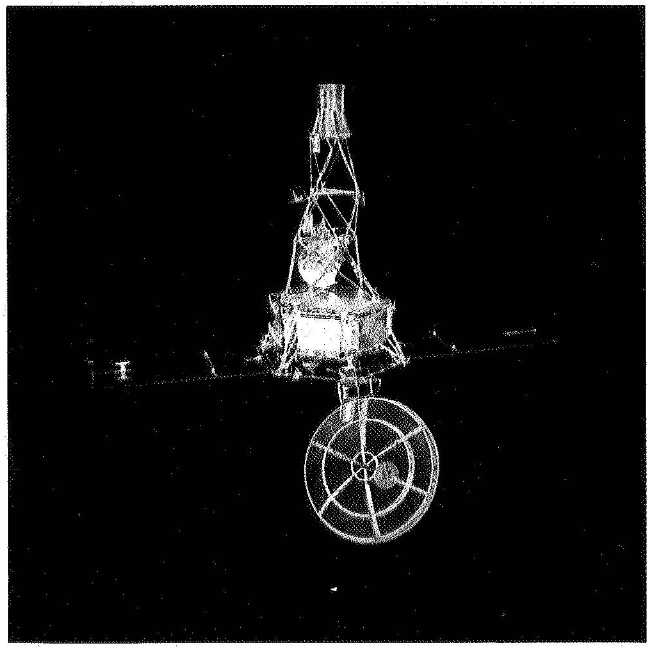
By 1961, it was apparent that Mariner A's launch vehicle would not be ready to meet the 1962 Venus launch opportunity, but that a creditable mission could be conducted with the Atlas/Agena, which would have flown several Ranger missions by that time. The problem to solve was designing, building, and testing a quarter-ton Mariner spacecraft in the time available.

Ranger I test-mission spacecraft (1961)

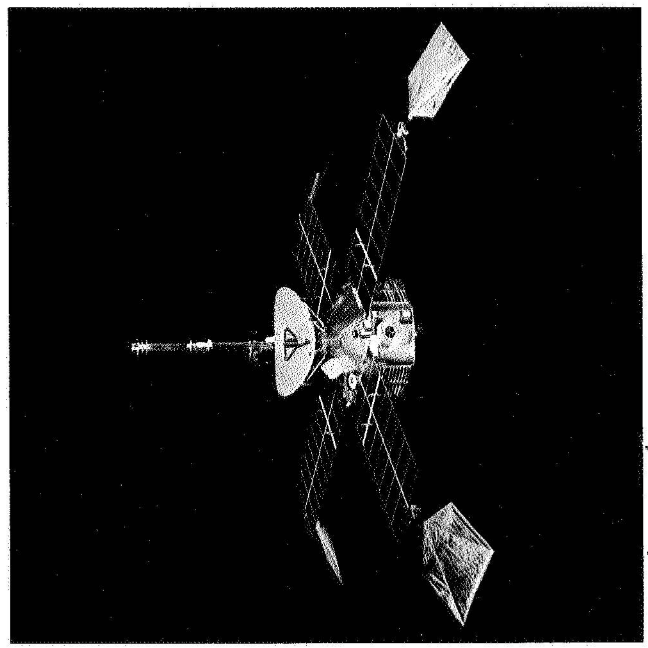


Mariner A spacecraft design (never flown)





Mariner II (Venus; 1962-63)



Mariner IV (Mars; 1964-65)

Thus the Mariner Venus 1962 Project was born. In ten months, the first successful interplanetary flight project in man's history was, in its various mechanical and human elements, organized, designed, developed, assembled, tested, trained, and readied for launch. The spacecraft included major elements of the Ranger lunar craft, combined with long-life assemblies and various devices and techniques developed for the larger Venus spacecraft, together with a modest but effective collection of interplanetary and planetary scientific experiments.

In the first Mariner 1962 launch, the rocket strayed irrevocably outside the safe launch corridor running southeast of Cape Canaveral and had to be destroyed. But Mariner II was safely launched, and for three months successfully kept its balance between heat, distance, and time before flying past Venus at a range of 21,000 miles. The period of flight operations, combined with the development and test phase which had come before, constituted a very intense educational experience for all the participants—a practical seminar and lab course in interplanetary flight. It was no sooner completed than the second course began — Mariner Mars 1964.

1964: TO MARS

This mission called for a completely new spacecraft, required to last through a flight of eight months to Mariner II's three months, and to range out into regions of declining solar energy instead of the blazing heat near Venus. A new science payload was called for, and the march of technology made many spacecraft advancements possible. Mariner II had been designed like Ranger in general form and many functions. For the Mars mission, shapes and methods were changed. All the lessons of the first planetary flight were applied, and the resulting spacecraft and mission designs had good prospects.

The first flight attempt was disabled when the nose fairing, intended to protect the spacecraft on its way through the Earth's atmosphere, failed, enclosing Mariner III in a death-grip. The launch vehicle team produced a fail-proof fairing in record time, and the second mission was begun just before the end of the possible launch period. The successful eight-month flight to Mars and the impressive photographs and other data returned from the planet provided unmistakable evidence that the Mariner approach to planetary flight was the right one.

After completing the Mars encounter and playing back its tape-recorded television pictures, the Mariner IV spacecraft gave no signs of being finished. Fields-and-particles measurements continued to come back, and the engineering telemetry showed the spacecraft fit for another year or two of flight. On October 1, 1965, the Earth would pass out of the beam of the high-gain antenna, which was fixed to the spacecraft frame at such an angle that it pointed at Earth during the later flight, encounter, and tape playback periods. The spacecraft would be out of telemetry range for many months, but would eventually approach Earth in the summer of 1967, coming as close as 29 million miles on September 8.

Nor was the spacecraft effort on the ground finished. Four spacecraft had been built (in addition to models simulating particular characteristics): only two had been flown. The proof-test model remained, but be-

MARINER COMPARISONS

Mission	Mariner II	Mariner IV	Mariner V
Months of preparation	11	24	16
Launch date	August 27, 1962	November 28, 1964	June 14, 1967
Days of flight and planet	109.5 (Venus)	228.5 (Mars)	127.5 (Venus)
Encounter date	December 14, 1962	July 15, 1965	October 19, 1967
Closest-approach altitude, miles	21,648	6118	2544
Launch vehicle	Atlas/Agena B	Atlas/Agena D	Atlas/Agena D
Spacecraft weight, pounds	446	575	540
Parts count	58,000	142,200	115,000
Experiments (flight instruments)	7 (7)	9 (7)	7 (5)
Communication distance at encounter, millions of miles	36	134	50
Total flight life, months	4½	37	5½ + ? ?

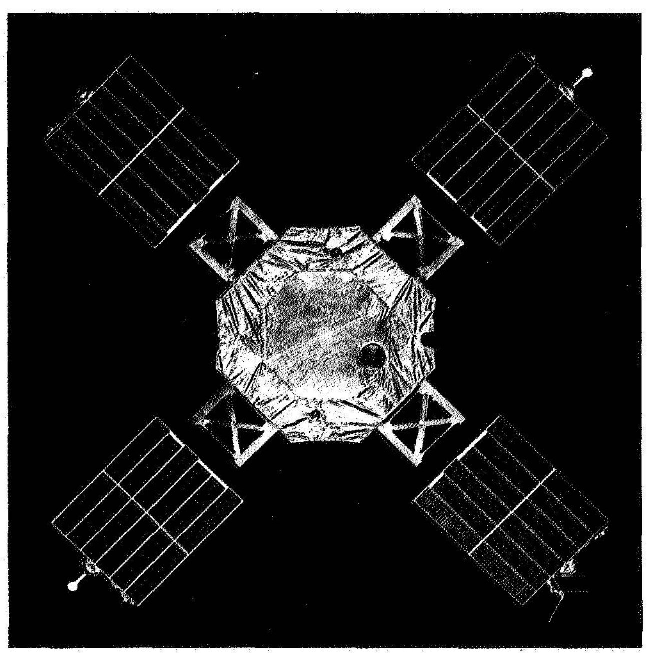
cause of the severity of its ground test and handling experience was not considered fully flightworthy. And the flight spare spacecraft, carefully packed and stored, waited for a job. Almost as soon as Mariner IV was well on its way, the planners began to consider the possibility of using the spare in a 1966 Mars mission. The near perfection of the Mariner IV flight discouraged a mere repetition, however.

A NEW CHANCE

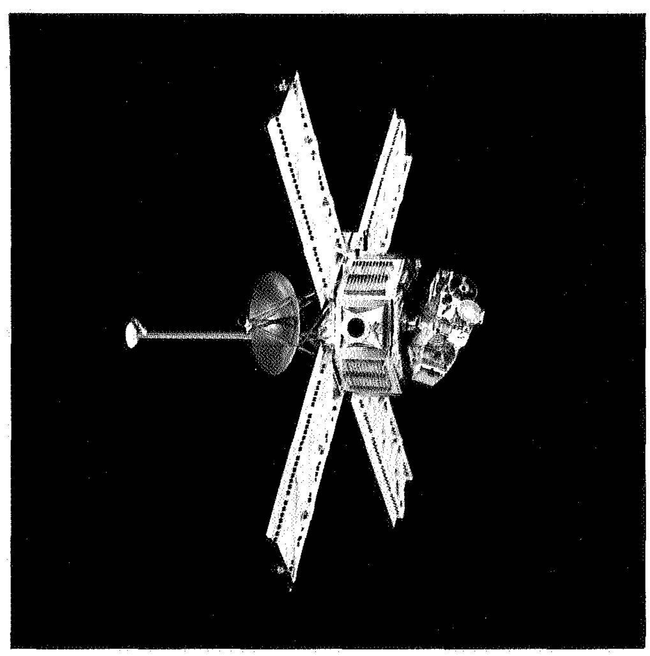
An early Christmas present to the Mariner family, to JPL, and to the United States arrived from NASA on December 22, 1965. It was the authorization for two new Mariner projects: one to conduct second-generation Mars investigations in 1969, and the other to return to Venus in 1967 using Mariner IV's spare. The Venus team would also be responsible for operating the original Mariner IV spacecraft when it returned, around the Sun, to the neighborhood of Earth.

The Mariner Mars 1969 team would build from the Mariner IV heritage a new Mariner generation, launched by the Atlas/Centaur and carrying several visual and spectroscopic instruments past the planet. First, though, a Mariner would return to the scene of the first flight from Earth to another world.

Mariner Venus 1967 spacecraft



Mariner Mars 1969 spacecraft



PLANET

In recent years, Venus has been thought of, and referred to, as a mystery world; but it has not always been so. There have been few periods in the history of science when the extent of man's ignorance has been recognized and accepted as much as in recent times. The evolution of our knowledge of the nearest planet has been a progress first from indifference to interest, and then from a confident assertion that it is Earth's twin through a diverging series of tentative theoretical models, successively less Earth-like, to the present concept of an inferno of great heat and pressure and negligible chance of life as we know it.

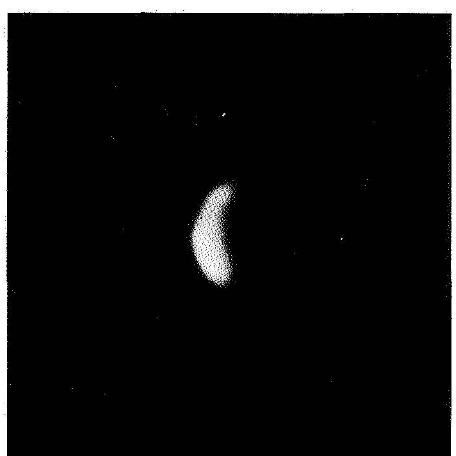
Venus entered recorded history four to five thousand years ago when the Babylonians observed its motion in the sky near the Sun. It was less useful in regulating the calendar than Sirius, however, and they and the Egyptians paid it relatively little attention. Pythagoras and his successors dwelt with more interest upon Mars and Jupiter in their attempts to construct cosmologies upon the naive principle that the Earth is the center of the Universe. Venus, almost alone among the planets, rides a very nearly circular orbit, which fits the demands of the neat but erroneous Pythagorean model; however, some of the classical and medieval observers were bold enough to suggest that it circled around the Sun.

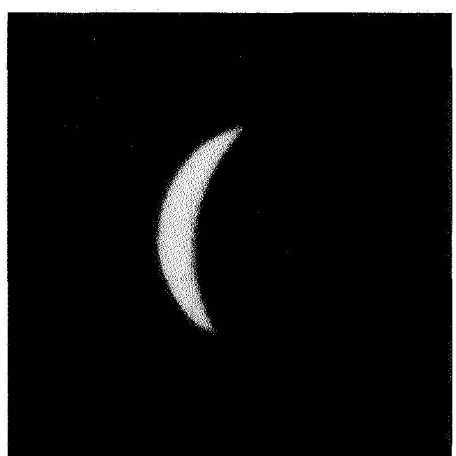
Similarly, because of its symmetry, Venus did not play a dramatic part in the overturning of the Pythagorean scheme; Kepler chose the knotty problem of Mars' motion to prove the ellipticity of orbital motion. Galileo observed with his telescope that Venus exhibits phases like the Moon, and reasoned that it must be a globe shining by reflected sunlight.

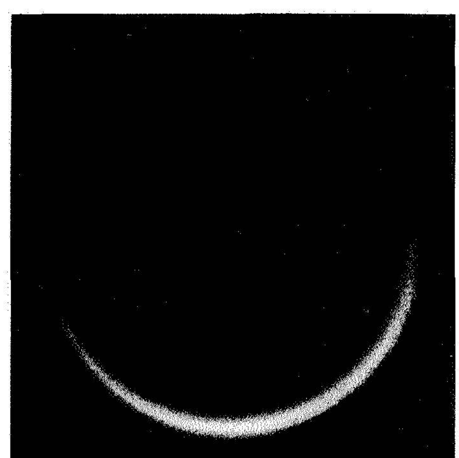
As optical instruments improved, the difficult task of studying this planet progressed rapidly. Since it is never more than about 45 degrees from the Sun, Venus must be observed either by day or close to the horizon —partly obscured, in other words, by scattered sunlight or by the exaggerated angular depth of the atmosphere. In addition, the closer Venus is to Earth—25 million miles every nineteen months—the less of its disk is illuminated.

Still, in 1643, the year after the death of Galileo, whose work had been discouraged and suppressed by the Church, a Jesuit professor named Riccioli first observed the ghostly illumination of the planet's night side, which he called "the ashen light." Within two decades, G. D. Cassini traced the movement of "surface features" and calculated Venus' rotation period to be just under 24 hours. This erroneous idea was to be supported on and off down to the present century, from a variety of measurements.

In the eighteenth century, concurrently with the early study of the surface features of Mars, the first maps of Venus began to be drawn. Through the time of Percival Lowell, best known for his championing of the study of Mars, visible or visionary features of the "surface" of Venus were recorded and discussed.







Also in the eighteenth century, Venus figured in the revelations of the Swedish scientist-turned-mystic, Emanual Swedenborg, as the homeworld of two races characterized respectively by humane innocence and savage cruelty. More recently, it was claimed to be a flying-saucer base.

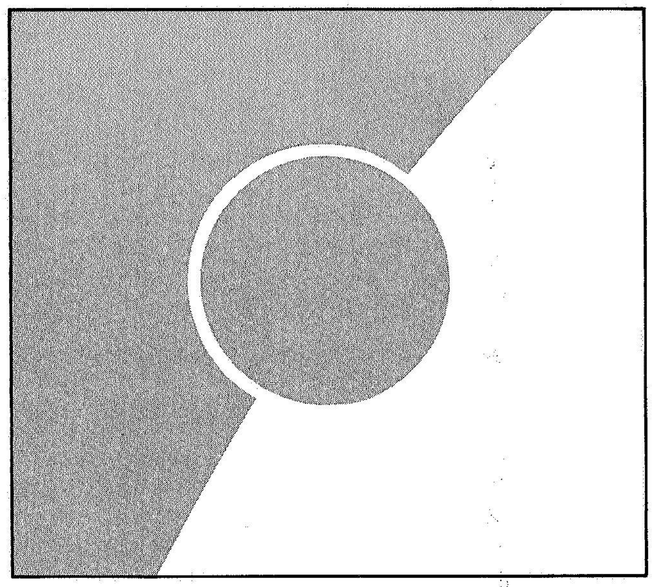
AIR AND CLOUDS

Venus passed in front of the Sun in 1761, an event which occurs only twice every 130 years; the transit was observed by the Russian scientist Lomonosov, who concluded that the planet has an atmosphere "equal to, if not greater than, that which envelopes our earthly sphere." This observation was repeatedly confirmed when the tips of the narrowing crescent were observed to extend beyond the half-circle they sketch on an airless globe such as the Moon. In the next few years, several observers reported sighting a satellite circling Venus, but it was never seen after 1764, and was put down as an optical ghost image.

By early in the nineteenth century, a number of observers had concluded that Venus' atmosphere was cloudy; some felt that features observed were in fact clouds, while others considered them a hazy view of the solid surface. In 1890, after two years' observation, Guido Schiaparelli concluded that the planet's day was equal to its 225 Earth-day year, so that the same side always faces the Sun, just as one side of the Moon does the Earth. Lowell supported this view with spectroscopic measurements, about the same time that Bepolsky, in Russia, asserted a 35-hour day for Venus. The many conflicting views of the planet serve to emphasize the difficulty of observing and measuring its properties.

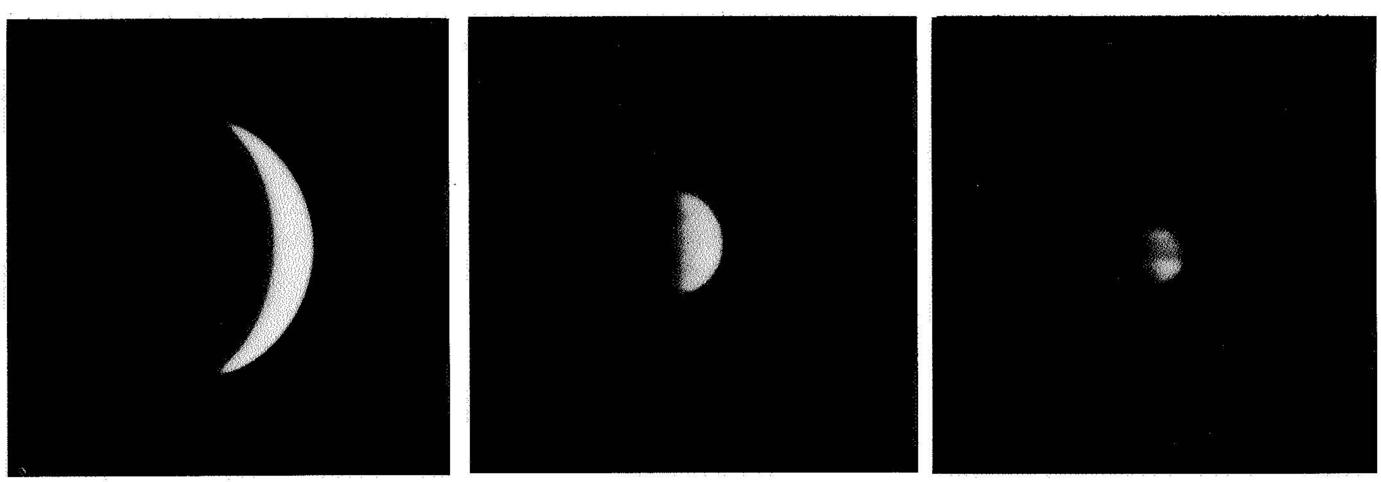
The presence of clouds led naturally to the idea of rain and moisture, and early in this century one of the most attractive speculations about Venus was that it is in a carboniferous era of swamps, cycads, and dinosaurs. The spectroscope failed to detect water vapor in the atmosphere, however, indicating a significant amount of carbon dioxide instead. This could hardly be the case if the surface were rich in life, which tends to use up carbon dioxide in plant cellulose and animal bones and shells.

Later measurements indicated the top of the cloud layer to be so cold that water would be mostly in droplet or crystal form, not vapor, and thus elusive to the spectroscope; and that the light-polarization properties of the clouds were consistent with such cold, watery clouds. A planet-wide ocean was hypothesized, teeming not with primitive saurians but with sparkling, natural carbonation.



Above, solar transit of Venus as seen in 1874 and 1882 reveals the atmosphere as a glowing ring.

Opposite and below, phases and changing apparent diameter are shown in six photographs made in 1964-66 at JPL's Table Mountain Observatory by C. F. Capen and J. W. Young. The first two were taken in near-ultraviolet light; the third picture, showing the ring, is in red light, the next in infrared; and the last two are in near-ultraviolet.



An alternative to fizz and cumulus was oil and smog, with hydrocarbons providing both the buffer between atmosphere and rocks and the visible shroud over the planet. But at this point, the problem of temperature arose: in 1956, the Naval Research Laboratory in Washington detected microwave radio emissions from Venus indicative of a very hot surface.

TEMPERATURE PUZZLE

Since Venus is in a position to receive twice as much solar energy as the Earth does, it might be expected to be somewhat hotter. Any body in the solar system, be it world or spacecraft, will be warmed by the Sun until it radiates as much energy back to space as it receives. The great preponderance of the Sun's output is light; but the planets and satellites, being cooler than the incandescent point, radiate primarily in the infrared, which borders the microwave radio spectrum. That there is some emission all across the spectrum, and that the frequency distribution is characteristic of the radiating material, makes spectroscopic analysis possible; but the burden of energy is carried below the visible frequencies.

In the centimeter-wavelength range, the implied temperature was about 650°F. But as measured with shorter radio waves, it was cooler—only about 200°F or less. Continuing radio-astronomy surveys generally confirmed this picture. The question then became a dichotomy: is it cool clouds over a hot surface, or a "hot" ionosphere over a cool surface? For Venus' proximity to the Sun alone was not enough to guarantee a torrid climate. Its reflectivity or albedo in the visible spectrum is about twice Earth's, so that it could possibly be absorbing even less of the solar output than we do, and if what are assumed to be the reflecting clouds are transparent to longer wavelengths, it could re-radiate freely, with the resulting temperature quite cool. The apparent high temperature observed would actually, in this hypothesis, be the measurement of a highly charged ionosphere.

One of the properties of carbon dioxide, which was apparently so abundant in Venus' atmosphere, is just the opposite: it is fairly transparent to visible light, but opaque to infrared. In sufficient concentration, this gas would serve as a greenhouse around the planet, trapping most of the energy which penetrated through the clouds near the surface, and accounting for the high temperature observed by radio.

The way to choose among these theories, or to support some new possibility, lay in improving the resolution of the observations. Up to now, the temperature measurements had been taken over the whole visible disk of Venus. Visual and photographic observations were finer in detail but inconclusive, and in any case not bearing on this problem. Venus would have to be scanned in the infrared and microwave regions. If the apparent high temperature was an ionosphere measurement, the disk would be brighter around the edge, where a greater thickness of the high-altitude layer was concentrated; if it was the greenhouse-heated surface, the center would be brightest.

This experiment could not be performed over a distance of 25 million miles or more. The scanner had to be brought close to the planet. Enter Mariner II.

CLOSEUP AND BREAKTHROUGH

Mariner II operated for four months in the interplanetary medium, returning scientific data on the environment for about three months; its radiometers scanned Venus for 35 minutes. The fields-and-particles instruments operated during the flight provided much of the early data needed for our understanding of the solar-system climate and weather as well as shedding light on the question of Venus; the radiometer data gave the nod to the greenhouse theory of the planet's thermal situation.

The spacecraft carried a two-channel microwave radiometer and a two-channel infrared radiometer, with the frequencies chosen to detect water vapor and carbon dioxide, and mechanical scanning to discriminate between surface and high-altitude temperatures. At mid-scan, the spacecraft was 23,000 miles above the surface and coming closer. Within an hour after the planet scan, the radiometers were recalibrated to assure accuracy.

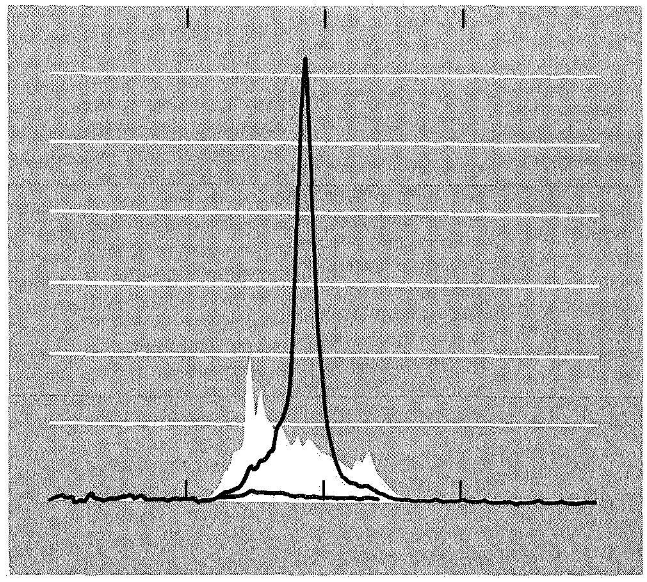
Magnetometer, plasma, and trapped-radiation data showed no planetary influence at the closest-approach altitude of 21,000 miles, revealing that Venus strongly differs from the Earth, whose powerful magnet traps solar energetic particles in a series of toroids around our planet and digs a gigantic cavity in the steadily flowing solar wind. Venus' magnetic field was found to be less than 10% as strong as Earth's by this negative datum.

PICTURES BY RADAR

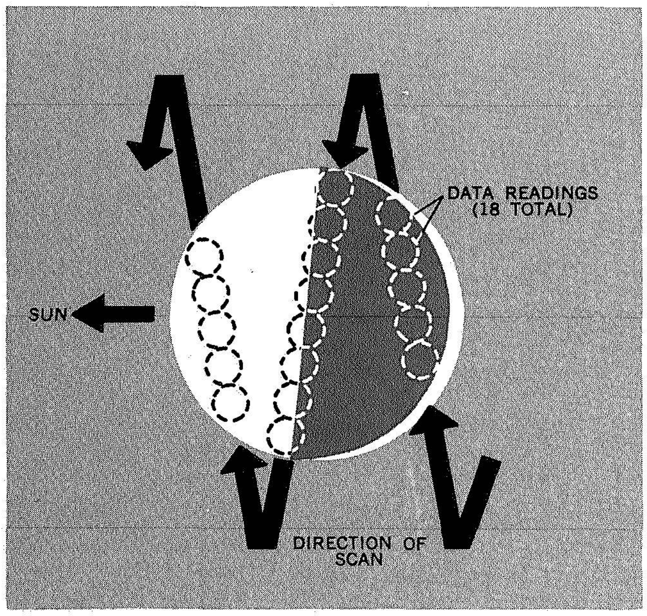
Meanwhile, the advances of radio astronomy and of radar had brought into being the technique of radar astronomy, which is simply analogous to using a flashlight at night. Radar echoes had been obtained from the Moon as early as 1946, and with the application of more transmitter power (by a factor of 10,000), the same was possible with Venus or Mars. A number of attempts were made, but it was at Goldstone that the echo from Venus was first heard.

Examination of the gross doppler frequency shift gave an accurate measure of the planet's motion in its orbit; study of the symmetrical shift, caused by the approaching and receding portions of the surface, could reveal the daily rotation rate.

Radar-astronomy studies of Venus have made great strides during and since 1962. The most dramatic was the detection in 1962, and the study and mapping in 1964 and 1966, of radar-roughness features of the solid surface of the planet. These were brought out by reversing the polarization of the Goldstone receiver to block out the glare of the primary radar reflection. Goldstein and Carpenter's measurements of the period of rotation of Venus, which is in a direction opposite to Earth's rotation, were refined from 250 ±50 days in 1962 to 250 ±9 in 1964. Tracking of recognizable radar features in 1966 and 1967 brought the figure to 243 ±0.6 days, a value confirmed by the Lincoln Laboratory in Massachusetts.



Radar spectrogram of Venus (after Goldstein). Black line shows smooth-surface brightness. Depolarized reflection curve, in white, shows roughness features, which move across graph as planet rotates, eventually reappearing at the other side.



Mariner II radiometers swept both dark and bright sides of planet, covering edges and center of disk.

This figure is the sidereal period; that is, every 243 Earth days, the same stars are over the same Venus meridians. The solar period is 116¾ days. Venus' rotation is apparently tagged to Earth's motion, for at each successive inferior conjunction, when Earth and the planet are closest, Venus presents the same meridian to Earth. The interval is about 575 days for us, and five nights for Venus.

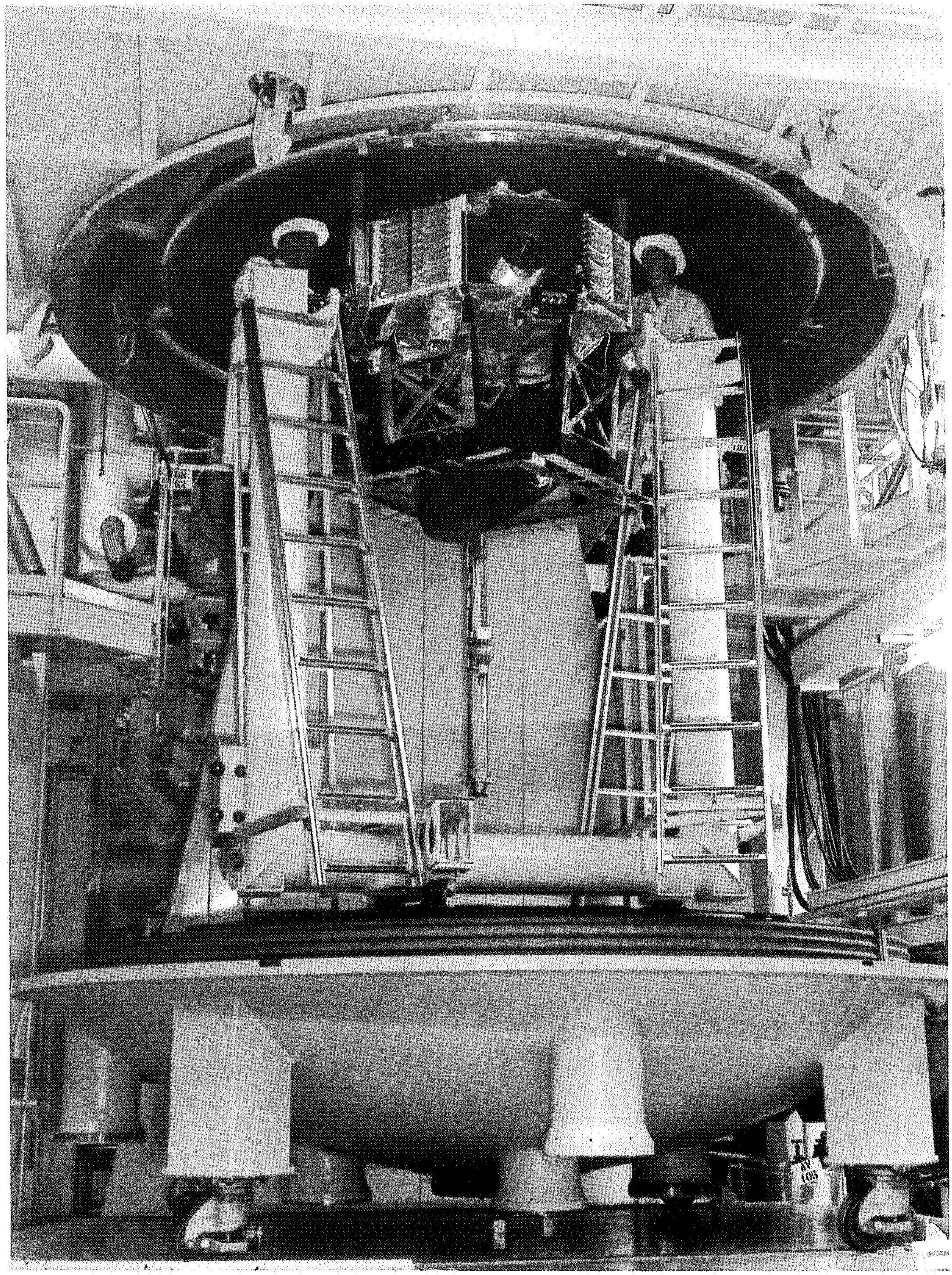
Some years of flight-data analysis, Earth-based observation, and theoretical study of Venus passed. The grand, endless cycle of data and analysis, of experiment and hypothesis, turned inevitably.

Thus it became time to come back to Venus.

PLANETARY COMPARISON
(Before Mariner V)

	Venus	Earth	Mars
Mean solar distance, millions of miles	67	93	141
Solar day, Earth = 1*	116.78	1	1.03
Sidereal day	243	1	1.03
Orbital period, Earth days	225	365	687
Mean diameter, miles	7520	7918	4230
Relative mass	0.82	1	0.11
Relative mean density	0.91	1	0.69
Albedo	0.60 – 0.75	0.40	0.15
Relative magnetic field strength	<0.1	1	<0.03
Surface atmospheric pressure, atmospheres	~10 – 100??	1	~0.008
Gross temperature regime	generally very hot	variable/moderate	variable/cold

*Period of rotation relative to the Sun, from sunrise to sunrise (ignoring atmospheric effects). The sidereal period is measured relative to the stars, as its name indicates, and is the "absolute" period of rotation. For fast-rotating bodies, the difference is small.



PREPARATION

The spacecraft which was destined to become Mariner V had been carefully stored away after the launch of Mariner IV. The proof-test model, kept available for analytical operations and tests until the Mars mission was successfully carried out, had also been put in storage. A new Atlas/Agena D launch vehicle would be ordered up, and similar launch operations at Cape Kennedy, Florida, for Lunar Orbiter in 1966–67 would help warm up for the 1967 Mariner. Mariner tracking and operations activities could be fitted into the Deep Space Network's active role in Surveyor, Orbiter, and Pioneer missions due in 1967.

The human element was more difficult. The dwindling Mariner team, many of whom had been around since 1961 without a break, had effectively dispersed with the October 1, 1965, closeout of Mariner IV; a few were left writing final reports. The Ranger team, similar in many respects to the Mariner crew, had disbanded earlier in the year. Somehow, around Christmas 1965, two new Mariner teams—for Venus in 1967 and Mars in 1969—had to be pulled together.

Members of the Mariner IV and Ranger teams provided the basis for the two new efforts. And, without wasting any time, the Venus team hauled their spacecraft out of storage and began to work on it.

DESIGNING FOR HEAT

The principal design changes necessary to convert the old Mars machine into a new Venus machine had to do with the Sun. In flight, the principal plane of the windmill-shaped spacecraft is perpendicular to the direction of the Sun. For the Mars mission, the Earth and Sun are on one side of this plane at all times; Mars is on the other side. The antennas are warm, in other words, and the camera is cool. Another feature of the Mars flight is that the spacecraft receives progressively less solar radiation on its way out from Earth.

Going to Venus, it's just the reverse. The Earth and Sun are on opposite sides of the windmill, and it gets hotter and brighter every step of the way to the planet. Therefore, the spacecraft design was turned over, so that the part of Mariner which was "down" at launch faced the Sun during flight. It was a new twist for JPL's family of fully stabilized spacecraft, although Lunar Orbiter works this way. It provided an inherently stable configuration in flight, however, since the center of sunlight pressure was behind the center of gravity, as in a parachute. In addition, the thermal geometry was improved: Mariner could present an almost unbroken reflective shield to the Sun.

Because Mariner would be flying closer to the Sun, the solar-panel area could be cut from 70.4 square feet to 43.6. To reduce heat transfer by reflection or scattering, the panels were spaced out two feet away from the octagonal spacecraft bus.

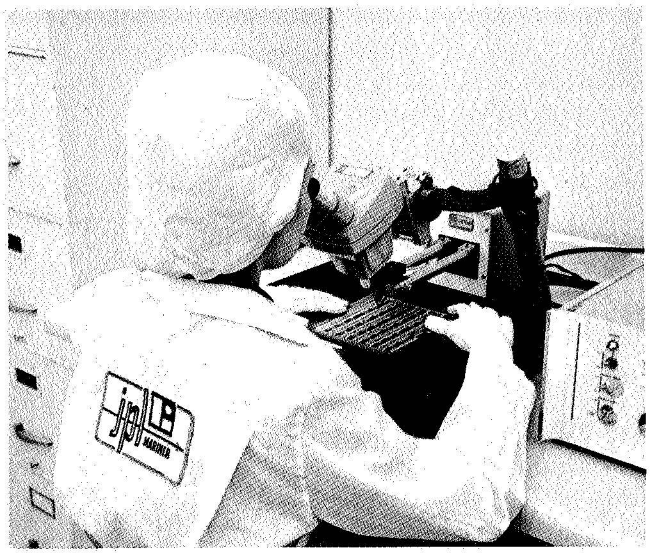
For spacecraft, extreme temperatures are undesirable. While the solar panels operate effectively at and above boiling temperatures, and the antennas are comfortable a couple of hundred degrees below zero, the battery and other electrical and chemical equipment must be kept within a temperate range.

The existing Mariner design was a sound one. The largest area presented to the beating sun was that of the solar panels. They converted about 10% of the light falling on them to electrical power, which was conducted into the spacecraft bus, eventually appearing there as

At right, Mariner V's aluminized plastic sunshield is shown unfolded to protect the octagonal main structure.

Opposite, Mariner V test spacecraft entering space simulator for test. Chamber will be pumped down to vacuum; walls will be refrigerated with liquid nitrogen; lamps and mirrors will provide imitation sunlight from top.

 heat. The rest was re-radiated by the panels in all directions. The bus itself was isolated from the panels, blanketed top and bottom in multiple-layer superinsulation, and belted with thermostatically controlled louvers which opened or shut as the temperature rose or fell, permitting fast heat radiation when they were open. For Mariner V, the sunny-side aluminized mylar blanket was extended by a folding octagonal sunshade, which held the total heat leakage into the bus at Venus to about 50 watts, including the energy coming in through the sun sensors and plasma probe.

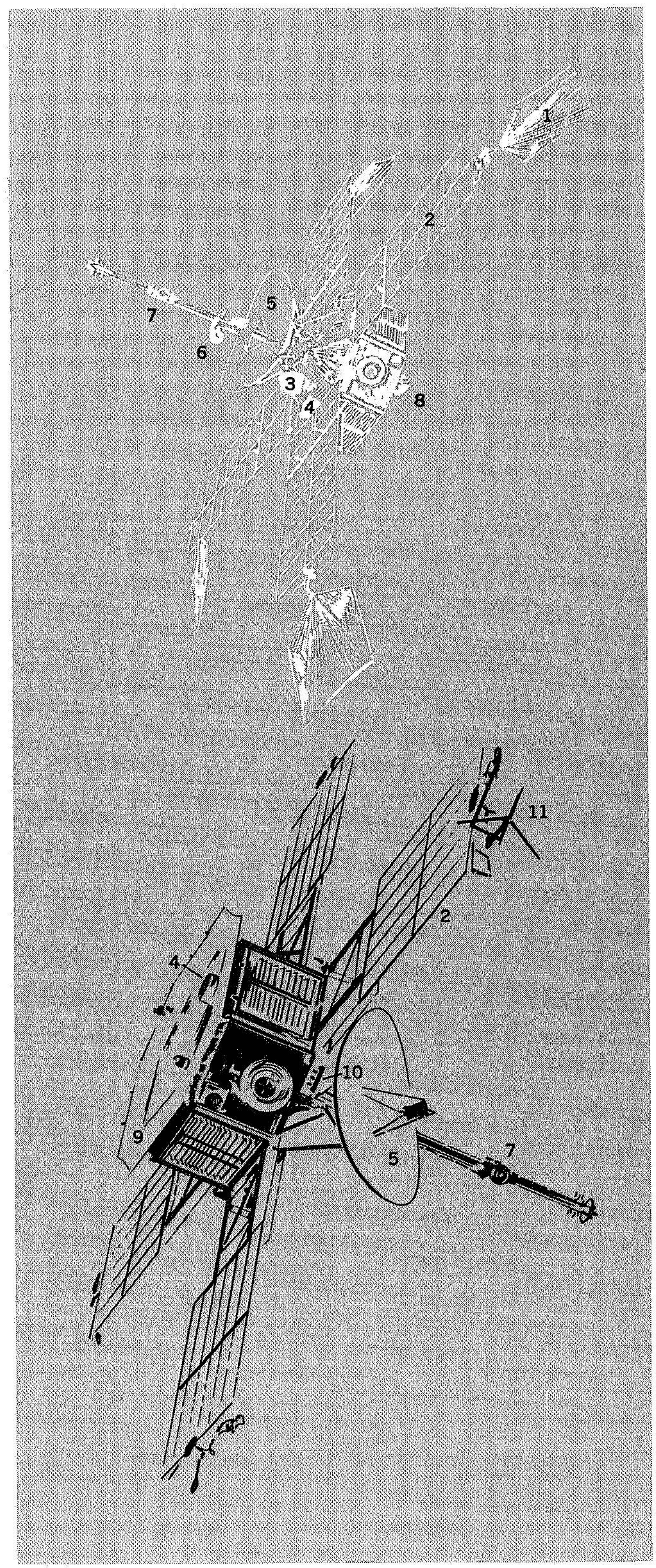


Fabrication of new data automation subassembly

Another factor to be considered in the Mariner '67 design conversion was the passage of time. Each component of the stored spare craft was at least two and a half years old when it became a component of the Venus mission spacecraft, but the old hardware worked perfectly when it came out of storage. One effect of time's passage was the advance of technology: Mariner's data automation system was obsolete, and could more readily be redesigned using integrated circuits than it could be reworked to incorporate the new functions of the Venus mission. The turn-around ranging technique, which had been a fledgling at the time of Mariner IV, would also soar to maturity in the 1967 interplanetary mission.

INSTRUMENTS FOR THE NEW LOOK

The scientific passengers booked for the Venus passage would naturally differ from those carried to Mars in 1964/65 and those taken to Venus in 1962. In the Mariner II mission, the thermal behavior of the planet had been investigated; now a close look at the solar-plasma interaction, the ionosphere, and the atmosphere of Venus was called for. The planet Mars has a visible surface, while Venus shows, so far as we can tell, only



Design changes to Mariner spacecraft for Venus mission, Mariner IV above, Mariner V below, Sun to left. (1) Solar stabilizing vanes deleted (spacecraft naturally stable). (2) Solar panels shortened, spaced away from spacecraft bus. (3) Cosmic dust detector deleted. (4) Plasma probe moved (to keep Sun in view). (5) High-gain antenna repositioned. (6) Ion chamber deleted. (7) Magnetometer retained on antenna mast. (8) TV, scan platform deleted. (9) Deployable sunshade added. (10) Bus-mounted ultraviolet instrument. (11) Dual-frequency receiving antennas.

thick clouds to Sun and midnight stars alike. Someday, when it is practical, and we can afford it, we shall take close-up pictures of the changing cloud patterns of Venus, return them to Earth, and study them. Eventually we shall reveal the shrouded surface of the second planet. But 1967 was too early. There was so much else to be learned, and the pictures would have come so hard and probably shown so little that they were foregone.

Instead, using some of the instruments inherited from the Mars project along with the spacecraft, and adding a scientific technique used previously in Pioneer, a two-part science complement was worked out. Both parts could operate any time during the mission, and return useful data on the properties of interplanetary space as well as those of Venus.

Fields-and-particles instruments are usually thought of in association with space environment studies. The space environment on which they were first turned, and which has been most studied, is the zone of influence of our own planet. The interaction of a planet's bulk, atmosphere, and magnetism with the solar wind and other interplanetary phenomena is one of the rich fields of planetary science. The helium magnetometer, plasma probe, and trapped-radiation detector, similar to those flown to Mars and to numerous instruments long in orbit, would jointly monitor the effect of Venus on the medium of the solar system.

Moving in closer to the planet, three other experiments would examine the atmosphere. An ultraviolet photometer would search in two spectral bands for evidence of atomic hydrogen and atomic oxygen clouds like those which hover invisibly around the Earth. Two radiofrequency propagation experiments would take the measure of Venus' ionosphere and atmosphere as the planet moved between Mariner and Earth; during this interval, the scientific measurements would be recorded on tape.

Radio occultation made its debut as an instrument for examining the atmosphere of another planet in the 1964 Mars mission, when the spacecraft communications link served as the scientific probe. But radiofrequency surveying of our own atmosphere and ionosphere dates back decades, and contributed, in early ionosphere surveys from ground stations, to the development of radar. A number of Earth-satellite studies, including the joint Canadian-American program using Alouette and Explorer spacecraft, have sounded the ionosphere by this means. Mariner V would use both the communications-link method of 1964 and a dual-frequency receiver. The latter, adapted from a radio propagation experiment of the Pioneer series, would receive UHF and VHF signals transmitted from a ground antenna.

Finally, the continuing effort, employed in each lunar and planetary mission, to draw new accuracy in our knowledge of the position, mass, and motion of each target body from the precise spacecraft tracking data, was formalized as the celestial mechanics experiment.

Testing Mariner's new three-channel ultraviolet photometer

Fabrication of lightweight structure for Mariner V solar panels

REBUILDING MARINER

With refurbishing, hardware testing, redesigns, and all, it was more than a year before hardware began to come together again in the Spacecraft Assembly Facility. There, Mariner spacecraft MV67-1, flight support, and MV67-2, the operational flight article, were assembled and tested.

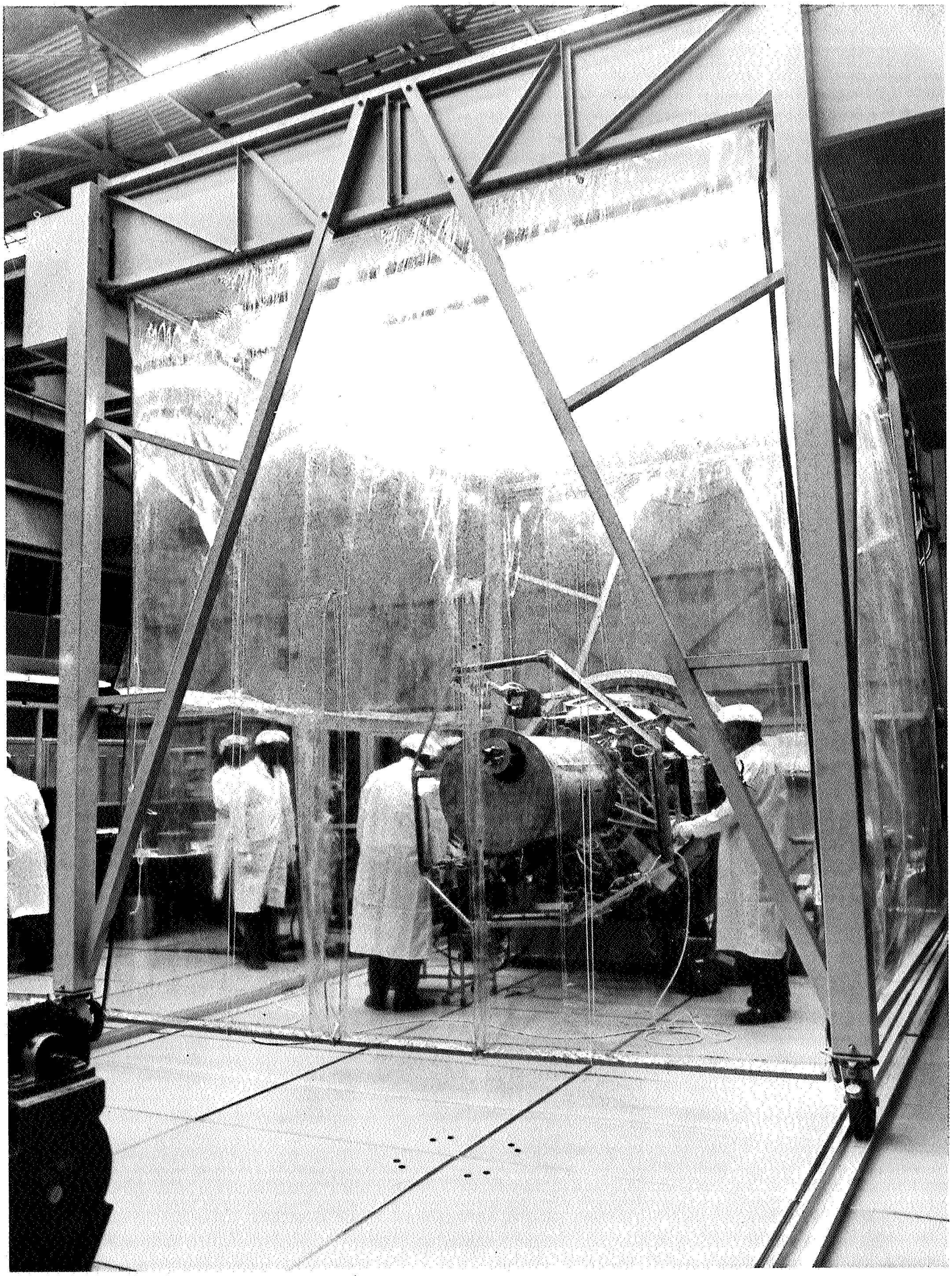
The new thermal design had to be checked out in a solar simulator, using a remake of the temperature-control model on which Mariner IV's thermal design had been proved. The antenna patterns of the new radio experiment were mapped at first using a reduced-scale model spacecraft. The Mariner IV electronics had been designed to be compatible with the magnetometer and other instruments, and with the S-band radio equipment. Now new equipment had to be checked for stray fields and radio noise, and the whole system had to be silenced in the UHF and VHF listening bands of the new dual-frequency receiver.

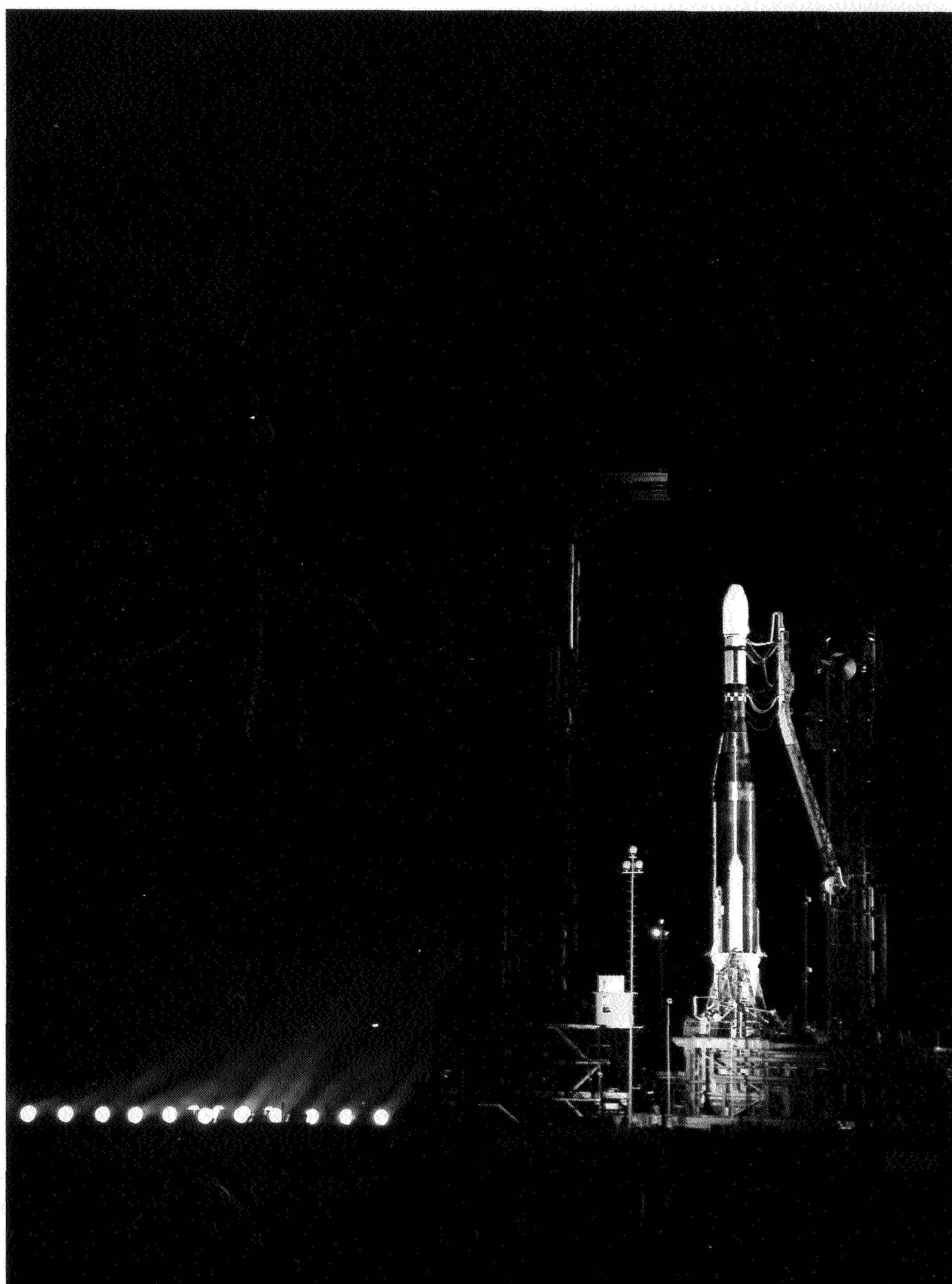
In its earlier version as the Mars mission spare, the flight spacecraft had been operated 540 hours in the Spacecraft Assembly Facility and the Environmental Test Lab. Now, as MV67-2, it accumulated 560 more hours of experience, including three system tests, vibration runs simulating the environment of launch, and eleven days in the space chamber. It was also matched with Agena hardware in a preliminary compatibility check, and operated with and through Deep Space Network communications equipment, taking commands and giving telemetry and science readings.

As always, careful records were kept of every "glitch." A new pattern began to emerge: fewer problems were cropping up, reflecting the fact that the spacecraft design and hardware had been this way before.

Other old hands were getting in shape for the big game. In San Diego and Sunnyvale, Atlas SLV-3 No. 5401 and Agena D No. 6933 were coming down the line, ready to meet the spacecraft at the Cape. In the California desert, around the world in Africa, Spain, and Australia, and in the chain of islands, ships, and land stations stretching southeast from Kennedy Space Flight Center, Mariner activities began again. Technicians of the Deep Space Network, Air Force Eastern Test Range, and Manned Space Flight Network were checking manuals and equipment for a refresher in the Mariner technique and an update for the Venus flight. The operations team was tuning up, even before the reacquisition of Mariner IV gave them a live spacecraft as a test article.

Thus, through the first several months of 1967, the men and machines that would bring a new Mariner back to Venus were beginning to work together.





LAUNCH

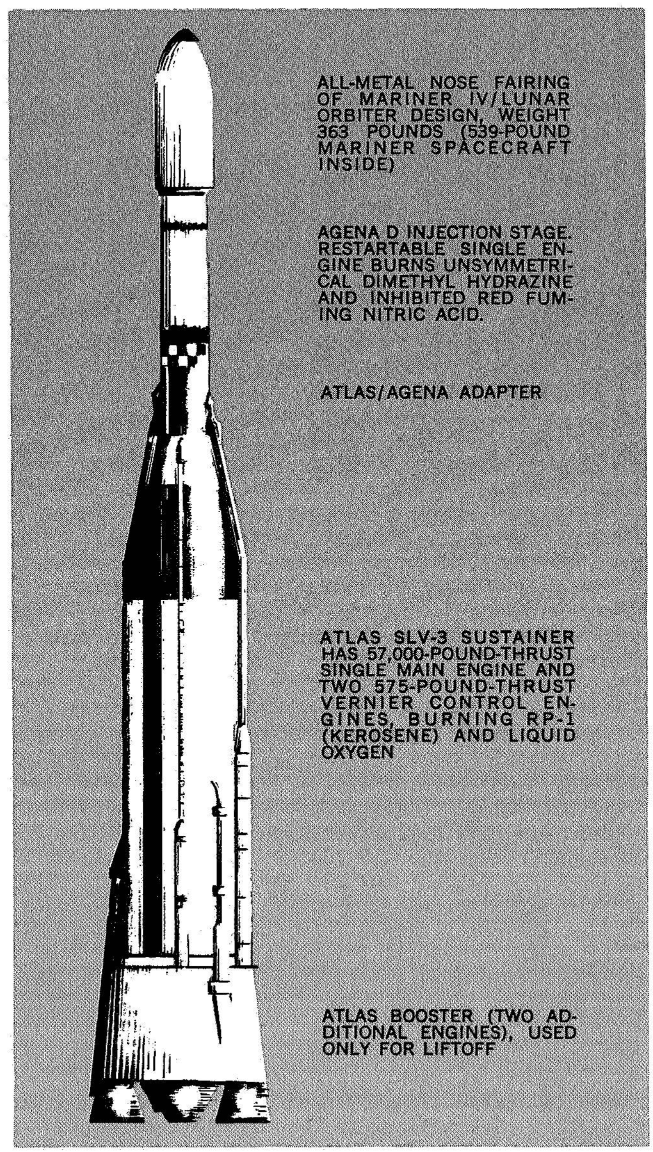
Spacecraft MV67-2 arrived at Cape Kennedy on May 1, 1967. The Spacecraft Test Complex, the data system, and the test and spare spacecraft, MV67-1, had been there a week; the Atlas and Agena more than a month. The Atlas was already standing tall at Launch Complex 12, ready to start its propellant loading test. The Agena was being checked out.

The Mariner Venus flight spacecraft had already qualified for its flight before being shipped to the Cape. Many hours of system and environmental tests at JPL, compatibility checking with Agena rocket hardware and deep space communications equipment, and a run-through of the countdown had rehearsed and refined the coming flight. Now, in the hangar and on the pad, the final dress rehearsals would be completed. When everything had been tested, calibrated, and verified, Mariner would join its multistage rocket vehicle for the launch.

THE INTERPLANETARY SHIP

The Atlas/Agena launch vehicle is a familiar workhorse in NASA programs. The vehicle standing ready for Mariner would be the 29th launched by the space agency, including nine Rangers, three Lunar Orbiters, the four previous Mariner liftoffs, and the rest used in launches of satellites such as the synchronous ATS, orbiting observatories, and Gemini docking targets. Truly an old hand, this combination was originally developed by the Air Force: Atlas as the first ICBM, Agena in the Discoverer satellite program, launched from Vandenberg on the Pacific Coast. The Atlas space launch vehicle is a 67-foot-tall, 10-foot cylinder most of whose bulk is devoted to kerosene-like fuel and liquid oxygen tanks which feed the 57,000-pound-thrust sustainer engine, the two 165,000-pound-thrust boost engines that help lift the loaded vehicle (276,903 pounds) off the ground, and the small vernier engines which help stabilize the rising rocket. The Atlas burns for about five minutes, lifting its eight-ton load free of the atmosphere, and then it too drops away. The Agena D, powered by a 16,000-pound single engine, is a mere twenty feet long, five feet in diameter. It must thrust twice, first adding enough velocity to achieve a satellite orbit, and then, after coasting around to the right spot, blasting itself and its spacecraft passenger into an escape trajectory prescribed by the particular space mission.

Actually, of course, every trajectory is an orbit, but most of them are distorted or interrupted in some way or other. Lunar spacecraft are often launched along elongated Earth orbits, and only a terminal thrust maneuver or the intervention of the lunar gravity, or of the Moon's surface, prevents them from looping eventually back around Earth. Interplanetary spacecraft are



 given a little more velocity in the right direction to make them satellites of the Sun or miniature artificial planets. Mariner V had to slide backward from Earth, losing enough velocity around the Sun to drop inward past Venus.

ZERO HOUR

The last of 32 daily operations reports was teletyped from the Cape to NASA in Washington and JPL in Pasadena on the night of June 13, 1967. Its principal message: "Countdown has started and all systems are green." All the checks and balances, all the calibrations and tests, all the rehearsals now were ended. At countdown zero, it was a minute after two in the morning, Florida time.

About two minutes later, the space vehicle stepped gracefully out of its booster skirt and settled down to fly on the Atlas main engine. Six and a quarter minutes past two, Atlas was finished. In the next few seconds, the aerodynamic spacecraft shroud and the empty Atlas dropped away. "Still looking good," reported the trackers. Separation of Mariner from its launch vehicle, to coast alone four months to Venus, came about 26 minutes after liftoff; Mariner was out of night, into the sunshine forever, by that time.

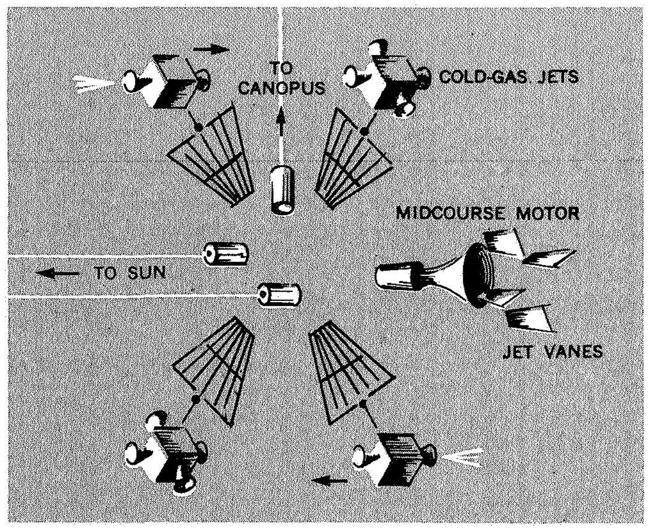
The list of tracking and telemetry stations, variously interested in Atlas, Agena, and spacecraft, reads like the program of a Caribbean pleasure cruise turned into a world tour. You can almost hear, as Mariner could not, the rhythm of drums, guitars, and the crash of a tropical surf. Grand Bahama, Bermuda, Antigua, Ascension Island, Pretoria, Johannesburg, Tananarive, Carnarvon, Canberra, Madrid, and finally, Goldstone. In the sky above each, Mariner flew, chattered its digital message, and passed on.

Mariner's science equipment came on shortly after separation from the Agena. About three minutes later, the solar panels and sunshade were released and allowed to open under spring tension. Within a quarter of an hour, the spacecraft had oriented itself toward the Sun and was rolling gently (about two rotations per hour) to calibrate its magnetometer. During the same several minutes, the Agena had turned to one side and then thrust off at an angle to be out of the way of the spacecraft.

TAKING THE BEARING

After sixteen hours of rolling, during which its magnetometer noted the magnetic bias imparted by Mariner itself against the background of the receding geomagnetism and the tenuous interplanetary field of the Sun, while the ultraviolet photometer observed around Earth the kind of phenomena it would seek at Venus, Mariner's Canopus sensor was turned on. The spacecraft central computer and sequencer had issued three internal commands. The first two had backed up the release of the solar panels and sunshade, and the turning on of the spacecraft attitude-control system, actually accomplished earlier by signals originating from spacecraft/Agena separation. The third internal command started Canopus acquisition, so that the spacecraft could be stabilized in three directions.

Acquisition stopped when a bright object was acquired, and the object was checked. Not Canopus—it was Earth, in fact—move on! A ground command re-started the search, and, about an hour later, Canopus was acquired. Stabilized in two directions and stern to wind, Mariner sailed out away from Earth. It was just over a day since launch.



Mariner attitude-control elements

Almost five days later, it was time for course-correction. At launch, the mission had been aimed to miss Venus by 43,700 miles—to ensure that no accident or error could permit either the spacecraft or the Agena to crash on the planet and risk its contamination. There had been a dispersion in the actual launch trajectory; tracking over the ensuing days had plotted the present course, and the change needed to bring Mariner within two to three thousand miles of Venus' surface. This change required the spacecraft to turn away from its Sun and Canopus orientation, hold its attitude fixed, and give the on-board rocket-engine long enough (17.66 seconds) to change the spacecraft velocity by 34 miles per hour. The commands were duly sent to the spacecraft, and stored in the central computer and sequencer. Then, at 21:24 GMT, June 19, the "go" command was transmitted from Goldstone to the spacecraft. About 45 minutes later, the spacecraft was correctly pointed, and the rocket flared out for the short period needed.

Then Mariner reacquired the Sun and Canopus, and sailed on, now accurately headed for its rendezvous with Venus.

VOYAGE

As Mariner V slipped along its corrected ellipse toward an intersection with Venus' orbit, the influences of the Sun surrounded it. The zone dominated by the Earth had been left behind in the first day or so; the small domain of Venus was far ahead.

Mariner was sailing across the radial pressure of sunlight, which like a thin but extremely stiff breeze pressed the spacecraft outward and off course, and the more massive but far slower solar wind carrying with it in a great flower-like spiral some uprooted strands of the Sun's magnetic field.

WEATHER IN SPACE

While the direct radiation takes several minutes on its journey from the Sun, the plasma travels for days, though its flow is more or less continuous, before reaching the spacecraft or the Earth. Sunwide variations in the plasma radiate out through the solar system like ripples in a pool. The energetic charged-particle effluvia from localized solar flares must climb the magnetic spirals as they spread in a narrow curved fan. These high-energy electrons and protons emanate from visible bright flares closely associated with sunspots; on reaching Earth, they cause magnetic storms, auroral displays, temporary disruption of long-range radio communications, and many other disruptive effects through major fluctuations in the ionosphere.

Sunspots were observed telescopically by Galileo in 1610, who deduced the Sun's rotation from their motion. The Sun rotates on its axis approximately every 25 days; relative to the moving Earth, this period becomes 27 days. The Sun is not a solid body, and spins faster at the equator than near the poles, with a difference as great as 40 percent between the period at zero latitude and 70 degrees above it.

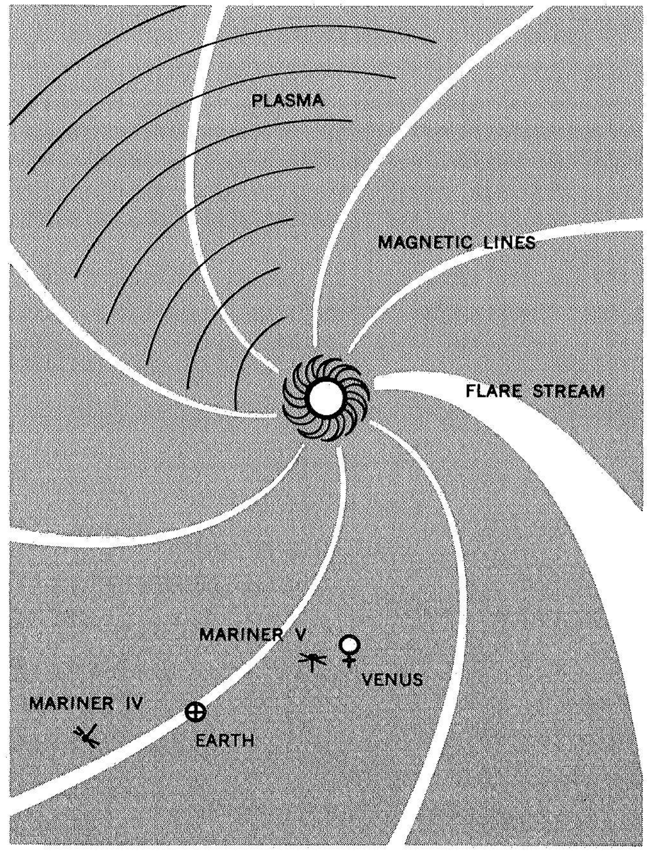
Transient fluctuations in the geomagnetic field were observed in 1722; discovery of the worldwide quality of large, irregular fluctuations called magnetic storms, and their correlation with auroras, followed in the next few decades. It was the nineteenth century before the study of sunspots was so advanced that their eleven-year activity cycle was correlated with the cycle of magnetic-storm activity, and the two phenomena were related. The first recorded observation of a solar flare took place in 1859; the flare was exceptionally brilliant, and was followed by an unusually intense magnetic storm. It was for spacecraft-borne instruments to show the full course of this passage.

A solar flare is a sudden brightening of a small part of the Sun's surface, usually associated with a sunspot, but much shorter-lived: a flare will last minutes or hours, to the spot's days and weeks. Visible and ultraviolet light are emitted; the latter will affect Earth's ionosphere. The flare spectrum extends from x-rays well down into radiofrequencies. Sometimes a plume

Spacecraft performance analysis team at Space Flight Operations Facility during the mission

of dense gas or plasma is emitted, which is visible, like a great geyser, if it occurs at the edge of the Sun's disk. It is the high-energy charged particles, pumped out along magnetic lines of force in an intense, narrow stream or pulse, that have the strongest effects. There are longer-lived, lower-intensity streams of an otherwise similar nature whose moderate effects are often observed to recur on the 27-day solar clock. But the trail of a flare comes suddenly, unpredictably, even without warning if the solar source is hidden behind the limb. The energy onslaught reverberates down through Earth's magnetosphere like a sonic boom, shivering the geomagnetic field and jittering the ionosphere.

Through much of its journey, Mariner V trailed the Earth in orbit. The particle streams, overtaking both, swept first over the spacecraft, then the Earth, then, beyond Earth's orbit, on to the ancient Mariner IV. At the two spacecraft, the storm winds from the Sun are observed directly in the trapped-radiation detector, and as disturbing influences on the more sedate phenomena watched by the plasma probe and magnetometer. On Earth, the flares are observed optically in solar observatories, and their effects are monitored in various laboratories; around the Earth, many satellites observe and map these phenomena.



Mariner in the solar environment

OBSERVER IN ORBIT

Mariner V observed its first proton event on the twelfth day of flight. Lingering activity detected in the first day or so indicated that another, larger event had occurred before launch. The prevalence of solar storms was considerably greater than Mariner IV had encountered in 1964/65, since the solar activity was increasing toward the 1968/69 peak.

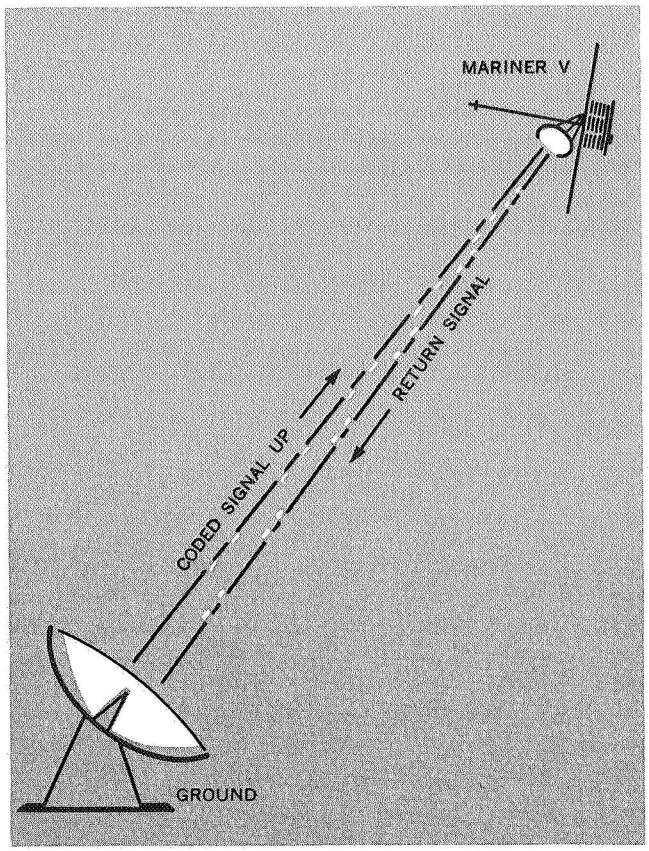
In mid-August, the two spacecraft and Earth approached alignment along a solar radius: Mariner IV's opposition came on the twenty-first, Mariner V's inferior conjunction a few days earlier. Late in September, the three bodies came close to association along the same magnetic spiral, permitting multipoint observation of particles moving along that path. The three bodies could never be closely aligned, since throughout the Mariner V flight the older spacecraft was eight to ten degrees above Earth's orbital plane, while the Venus spacecraft was more than two degrees below it through most of August and September.

Mariner was never intended to be a stellar observatory. Still, it seemed a pity to turn on the ultraviolet photometer only for a couple of hours near Venus. Its three phototubes cover the long-wave ultraviolet spectrum in such a way that spectral lines of atomic hydrogen and oxygen can be identified and these elements measured: this was done near Earth during the first day of the mission. During the four-month flight, the instrument stayed in operation, looking roughly back along the spacecraft's path and outwards, along a line Venus must cross on encounter day. A number of stars crossed that sweeping line; many more had swum into view during the first day out, as the instrument swept past Earth's hydrogen cloud and on in a full circle. These readings not only served to check the stability of the instrument (the roll survey was repeated in November, 180 degrees around the Sun from launch, when the same ring of stars was visible) but also opened a spectral window which is blocked to Earth-bound astronomers by the ozone layer in our atmosphere.

No quantitative scientific conclusions have been released on the inflight measurements obtained by Mariner V, and the simultaneous observations made by Mariner IV. The principal reason is the sheer bulk of data; a more subtle constraint is the need for correlation and comparison, not only between the Mariners, but with concurrent Earth and satellite data, and measurements from the two Pioneer interplanetary spacecraft. Correlation is a task whose magnitude increases exponentially with the increasing data sources.

MARINER CALLING EARTH

Throughout the flight, as Earth turned beneath the spacecraft, and one tracking station transferred the signal to another, and one operations shift followed another, no crisis arose to galvanize the energies of the



Above, special coded signal sent to the spacecraft and returned permits calculation of range.

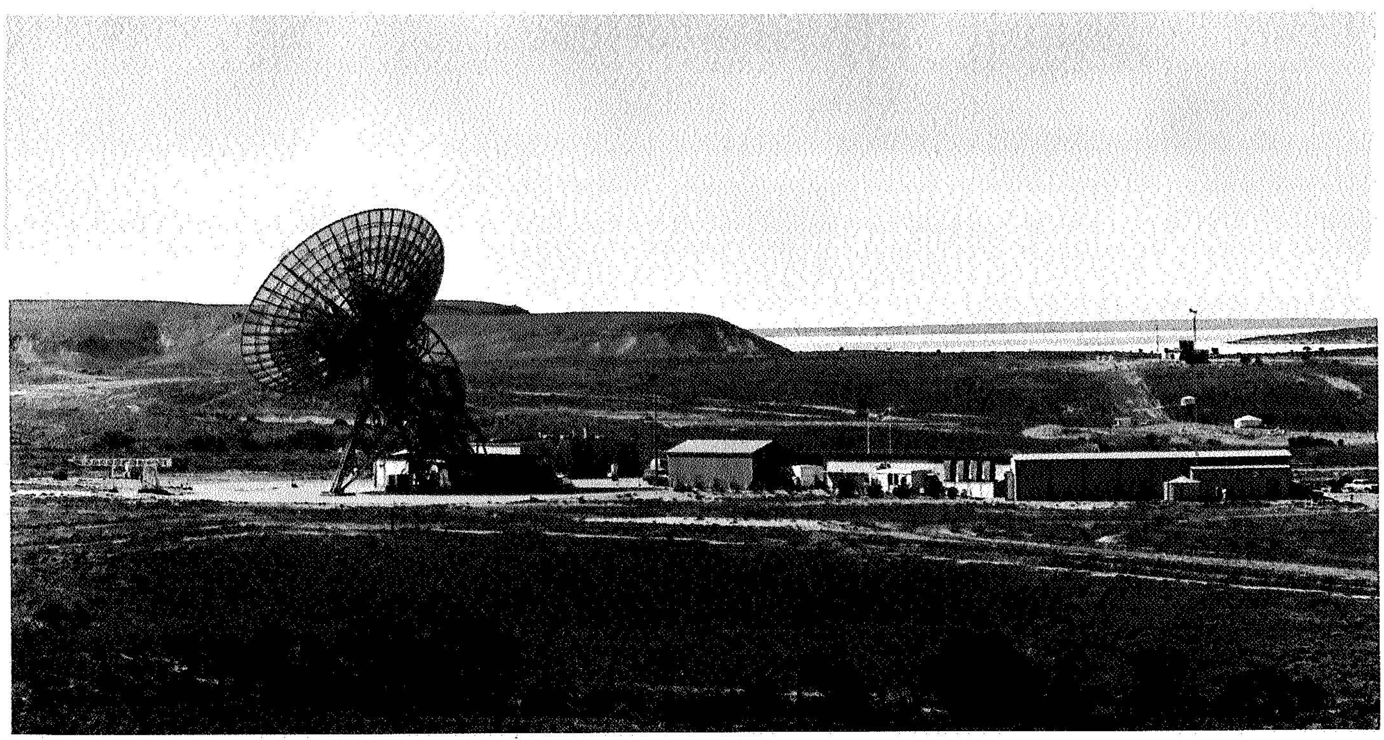
Below, deep space tracking and communication station at Woomera, Australia

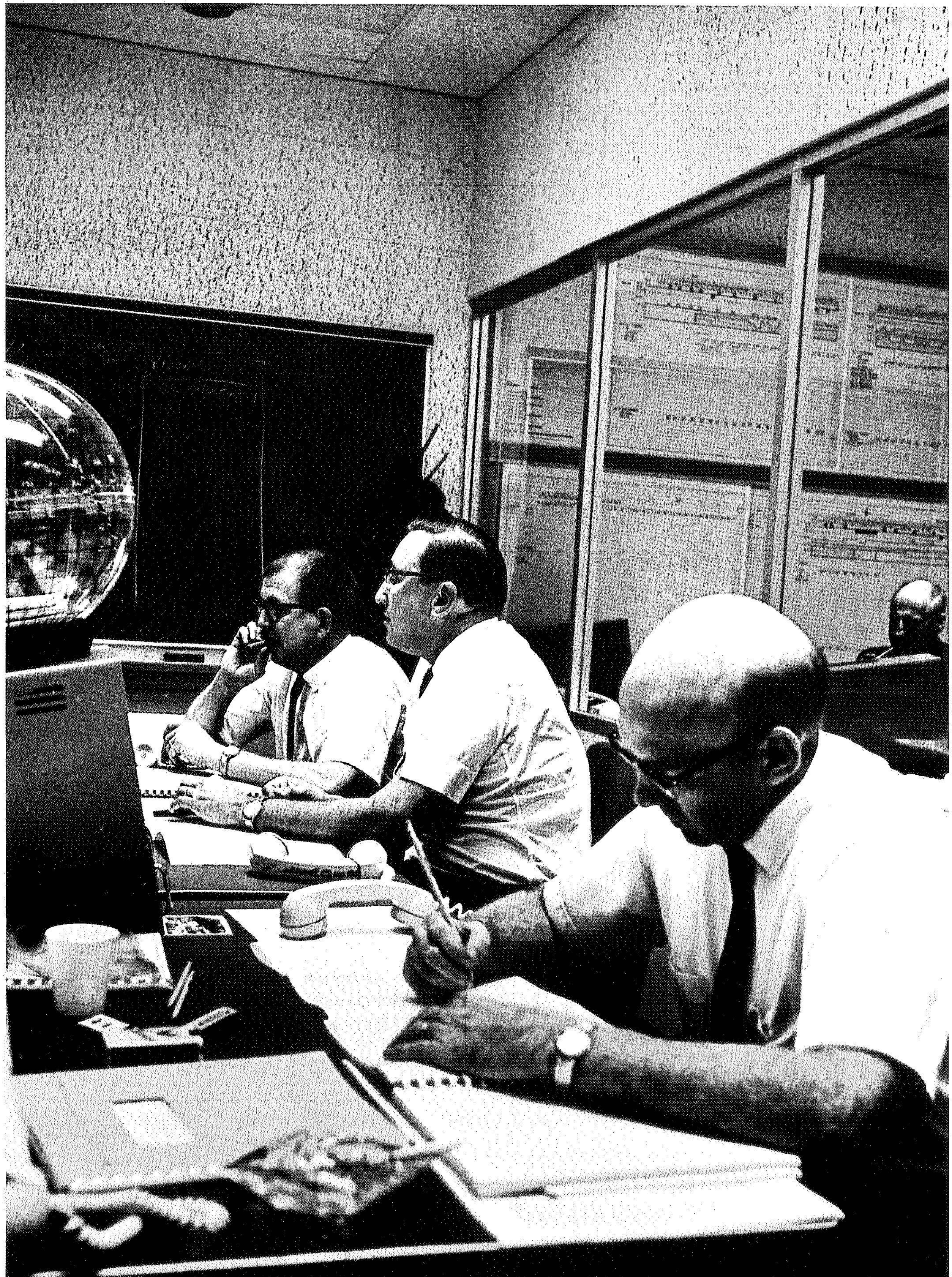
engineers. In the deep space range, the two Mariners and the two Pioneers almost quartered the sky, each sending its individual message of scientific clamor and engineering quiet.

Mariner V provided the first exercise of the turn-around ranging technique at planetary distance, although ranging experiments and operations had been carried out at satellite and lunar ranges. The basis of the radio tracking and navigation which characterized previous planetary missions had been the precise determination of the velocity between spacecraft and tracking station by measuring the frequency shift of the coded signal sent up to the spacecraft at about 2100 megahertz*, converted to about 2300 megahertz, and returned to the ground station. The velocity accuracy obtained by this method is a small fraction of an inch per second; but, in reckoning the position of the ship, the baseline must be drawn all the way back to the position near Earth. Ranging provides an accurate baseline at planetary distance. It simply requires timing the return of the signal; since radio waves propagate at 186,000 miles per second, the time is short, and must be measured with great precision. The inherent accuracy of ranging in the Mariner V mission was in fact about 20 feet in 50 million miles when the spacecraft was close to Venus, though the accuracy employed in calculation was several hundred times as great.

Four months of flight passed quietly; Mariner V and Venus rushed toward their October encounter.

*A megahertz is a million cycles per second. The FM broadcast band is centered about 98 megahertz.





CONTACT

Mariner Venus encounter operations began at 0249 GMT, October 19, 1967, with the transmission from the Woomera deep space tracking station in central Australia of a DC-V25. This direct command, expressed digitally (the form in which it was sent) as 110 010 01000, turned on the spacecraft tape recorder, which would retain planetary scientific data taken when Mariner V passed behind Venus. It also energized the terminator sensor, which would initiate, also during occultation, the switching of the spacecraft's reflector antenna to a new pointing direction. The command had the further effect of turning on the scientific instruments, in case they were not on already.

This ground command was designed as a backup to an internal command from the spacecraft's central computer and sequencer, the first of two internal encounter commands which would set in motion the automatic spacecraft and scientific-instrument operations necessary for the observation of Venus. As a matter of operational scheduling convenience, the ground backup command came first; but about two hours later, the internal actuation was issued on schedule. In about twelve hours, the actual encounter of Mariner V with Venus would begin. The spacecraft was setting in the sky above Woomera, and rising over Cebreros station in Spain; the Australians would not see it again until after it emerged from behind Venus.

YESTERDAY THE CAPSULE

The day before, Mariner's flight rival, the Soviet spacecraft Venera-4, had reached the common target. Venera's objective was not, like Mariner's, to survive the encounter: the Soviet spacecraft bus destroyed itself like a meteor in the atmosphere of Venus, while an 850-pound capsule was ejected, slowed, and then suspended from a parachute to drift down for 95 minutes through the atmosphere, obtaining pressure, temperature, and density measurements, and sampling the atmosphere at two points. According to Soviet sources, it continued to transmit until impact on the planet's surface; then it fell silent, possibly destroyed by the heat, but with a remarkable mission completed.

MARINER VENUS ENCOUNTER EVENTS

Event	Primary source	Backup source
Turn on tape recorder	Internal MT-7	Ground DC-V25
Turn on terminator sensor	Internal MT-7	Ground DC-V25
Switch to all-science data	Internal MT-8	Ground DC-V24
Turn on planet sensor	Internal MT-8	
Ranging operations period	Ground DC-V9 (on/off)	—
Turn on Stanford transmitter	Ground operation	—
Turn off ground transmitter	Ground operation	—
Start recording science data (two independent starts)	Planet sensor + Clock B	Ground DC-V16 + Clock A
Antenna pointing change	Terminator sensor	Ground DC-V16 + Clock A Ground DC-V22 (later)
Stop recording and switch to mixed data mode	End of tape in recorder	Clock A + Clock B
Ranging operations period	Ground DC-V9 (on/off)	Internal timer (off only)
Switch to playback data mode	Internal MT-9	
Tape playback	Internal MT-9	
Stop playback	Ground DC-V2 and DC-V28	—

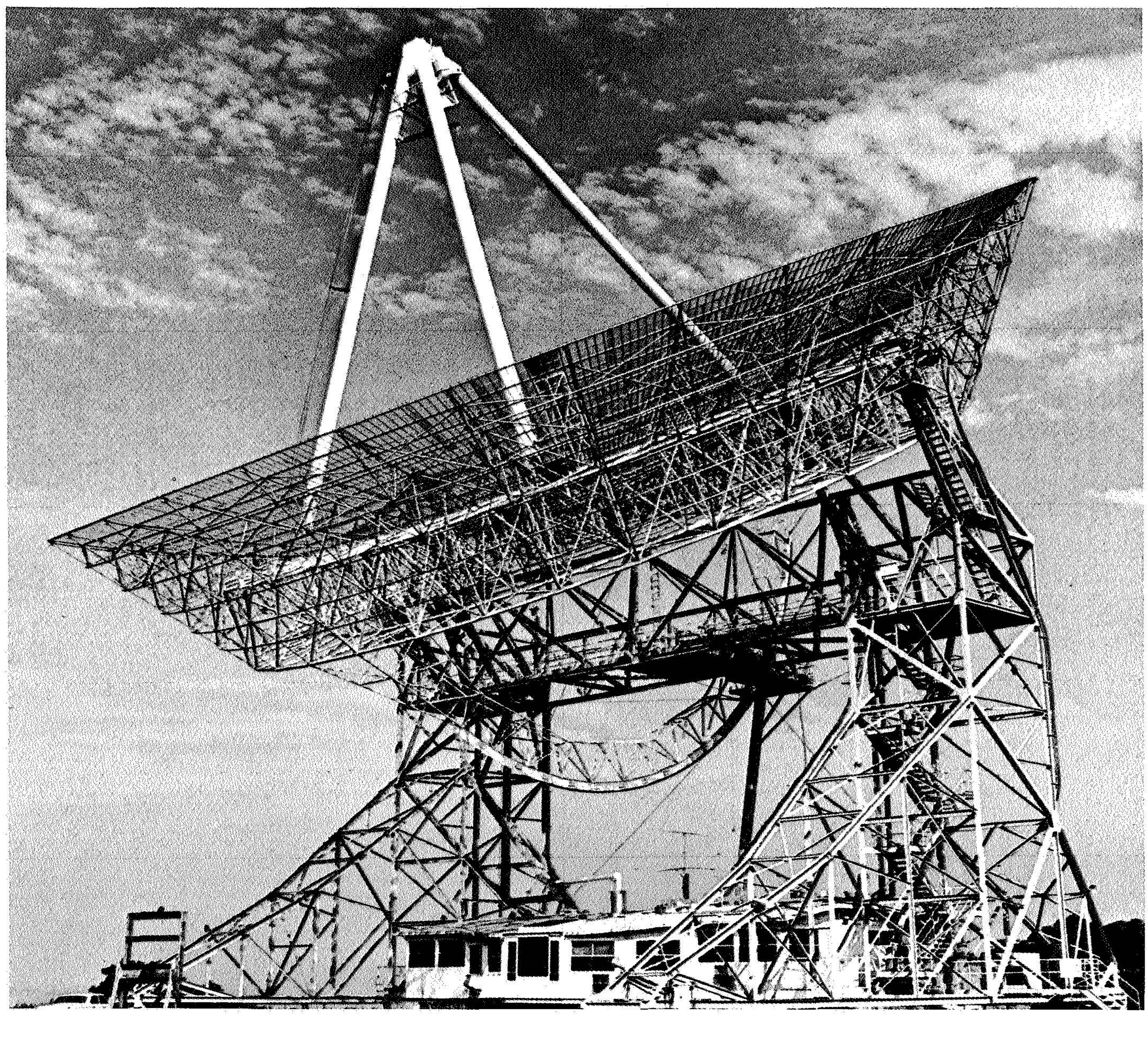
Notes: MT stands for master timer, a device in the central computer on the spacecraft.
DC stands for direct command, a coded signal transmitted from Earth, and V distinguishes Mariner Venus commands from those used for the Mariner IV Mars mission.

Meanwhile, Mariner's far different encounter with the planet was being prepared. The second half of the encounter initiation was carried in duplicate by a ground command, DC-V24, sent up from the Cebreros station at 1050 GMT, and an internal command issued half an hour later. At this point, the spacecraft telemetry to Earth was changed from a two-to-one mixture of science and engineering information to the all-science format, and the planet sensor was energized. The sensor would automatically begin the encounter sequence of measurement and recording operations when Venus came into view.

Around the same time, Earth's rotation brought Mariner V into view above the California horizon. Near Stanford University, a team supporting the dual-frequency radio experiment pointed their 150-foot reflector antenna at the spacecraft and began to transmit VHF and UHF signals to a special receiver on the spacecraft. At Goldstone, in the desert east of Los Angeles, the 85-foot antennas of the Pioneer and Echo sites and the 210-foot reflector of the Mars station were turned toward Mariner V. In New Mexico, an Aerobee rocket was being launched to carry out an Earth-based parallel to Mariner's UV experiment.

The several teams of technicians, engineers, and scientists who made up the remote-control crew of Mariner had rehearsed long and carefully for this day. The four months of flight and the reacquisition of the veteran Mariner IV had provided general practice for the tracking station crews and central coordinators of the Deep Space Network, the Mariner mission operations system, and the scientific teams. Special tracking operations with Mariner IV had given the Network additional training and testing. A series of five encounter

Dual-frequency transmitting antenna in Northern California was the ground half of the radio-propagation instrument.



tests in September and early October had pitted the wits of the operators, the readiness of the equipment, and the completeness of the plans against simulated spacecraft events, including programmed failures generated through the flight support machine, MV67-1, operating on a stand in the spacecraft assembly area.

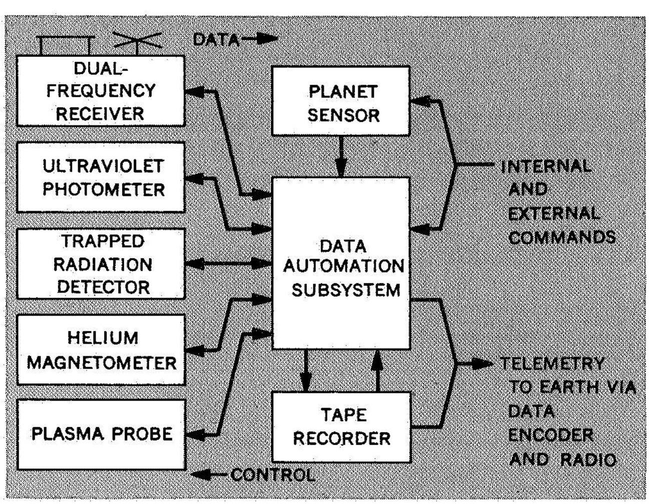
CLOCK-WATCHER

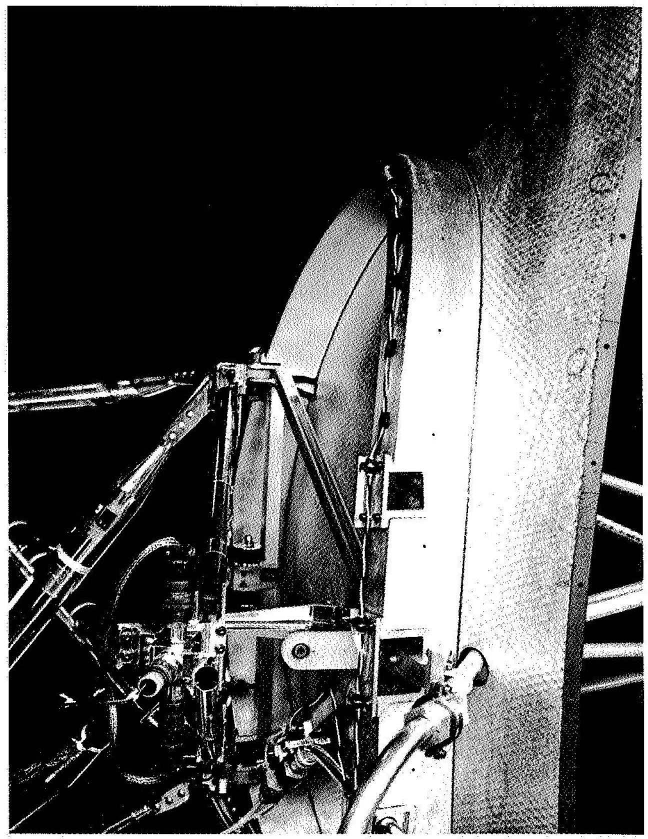
The encounter sequence is controlled within the spacecraft by the scientific data automation system, whose long-term function it is to process the outputs of the five instruments for return to Earth on the telemetry link. The general mission sequence was built into the central computer and sequencer, which was in fact the source of the internal encounter start commands. One recipient of these commands was the data automation system, which governed the encounter activities through two clocks.

The primary sequencer, Clock B, is activated by the planet sensor. It then starts tape recording, feeding ultraviolet photometer, trapped-radiation detector, and other signals to one track and the dual-frequency data to the other tape track. Finally it stops the recording operation, backing up an internal tape-recorder signal. The backup sequencer, Clock A, duplicates the outputs of Clock B, and also those of the terminator sensor which trigger the squib-released, spring-powered movement of the high-gain antenna while the spacecraft is occulted. This backup clock is set by a ground command, DC-V16. The command was scheduled to be sent to the spacecraft some three hours before closest approach; unfortunately, a loose connection in the ground-based command processor and timing equipment caused rejection of the command, and it was transmitted half an hour late, at 1501:43 GMT. Thus, Mariner V encountered Venus under control of the primary sequencer alone; it worked perfectly.

About an hour after Mariner had set in Spanish skies, so that only the Goldstone stations were tracking, the

Mariner V onboard science subsystems



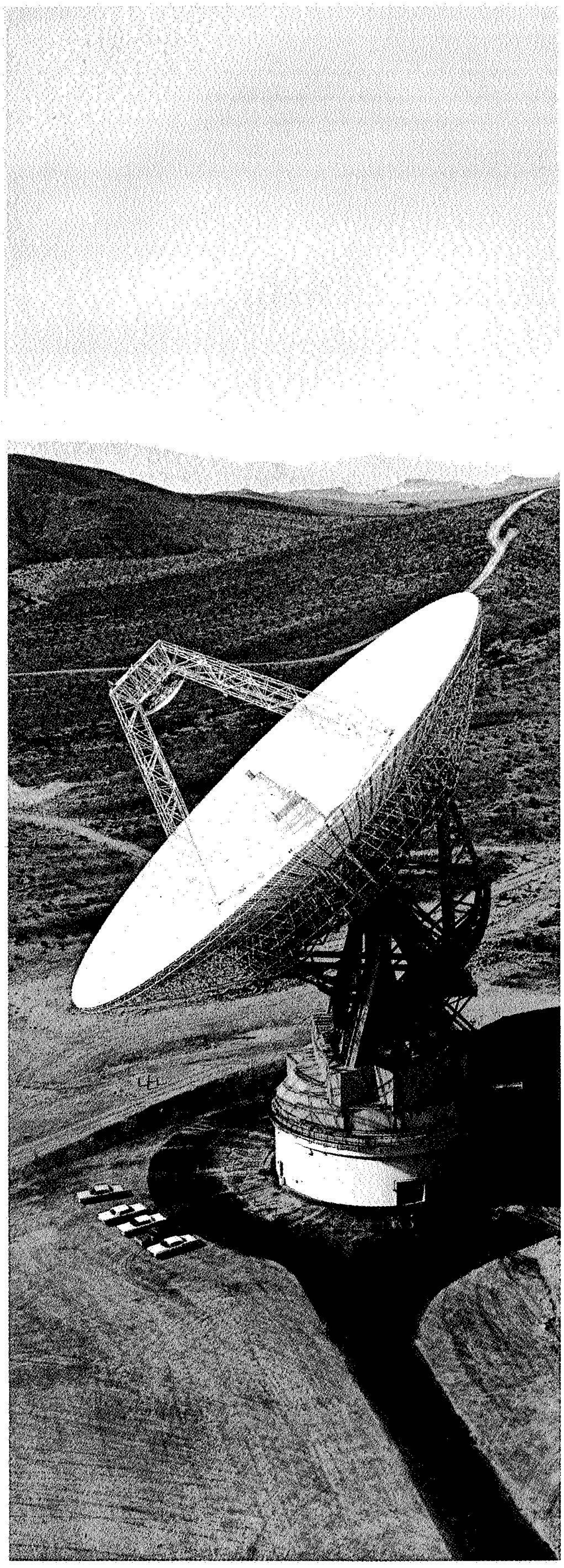


Mechanism of antenna pointing-angle change: when squib fires, pin-puller at left releases socket (center), allowing antenna to spring to right (shown opened).

planet sensor detected Venus; it was 9:34 in the morning, Pacific Daylight Time. The spacecraft was about 45 degrees ahead of the Sun in the sky; it would be near maximum elevation for Goldstone throughout the critical period.

The condition in which Mariner V would approach Venus, and pass behind it, had been considered with care. The attitude-control system had been set to minimize the chance of a disturbance which might twist the high-gain antenna away from Earth. In the normal cruise mode, if the spacecraft obtains evidence that it has rolled away from its Canopus alignment, the gyros drive the spacecraft around in a roll search until it senses a star sufficiently bright to make it stop and lock up. A false stimulus for this move could be optical, or it could be a temporary electrical anomaly. Either false stimulus was believed more likely than that Mariner V would be physically turned away from Canopus, and therefore this mode was disabled. Mariner IV had journeyed around the Sun in this non-gyro mode, and it was considered the safest way to encounter Venus.

Mariner IV had also been occulted by Mars in the two-way tracking mode. When the signal coming up from Earth is cut off abruptly, the radio switches to an internal oscillator for its frequency control, and during the warmup period, the frequency drifts somewhat



Deep Space Network's 210-foot Mars Station

before it settles down. In order to have the most stable frequency transmitted while Mariner was going behind Venus and emerging on the other side, and also to have the complicated atmospheric perturbations occur only in the single beam transmitted to Earth, the link was converted from two-way to one-way several minutes before occultation.

ARRIVAL AT LAST

About twenty minutes after Venus appeared to the planet sensor, its zone of influence began to register on the scientific instruments. Changes in the readout from the plasma probe and magnetometer, transmitted directly to Earth and also tape-recorded aboard the spacecraft, indicated contact with the plasma shock.

Closest approach came at 1734:56 GMT. Over the next few minutes, the radio links between Mariner V and Earth were smudged out, one by one, as Venus came between them.

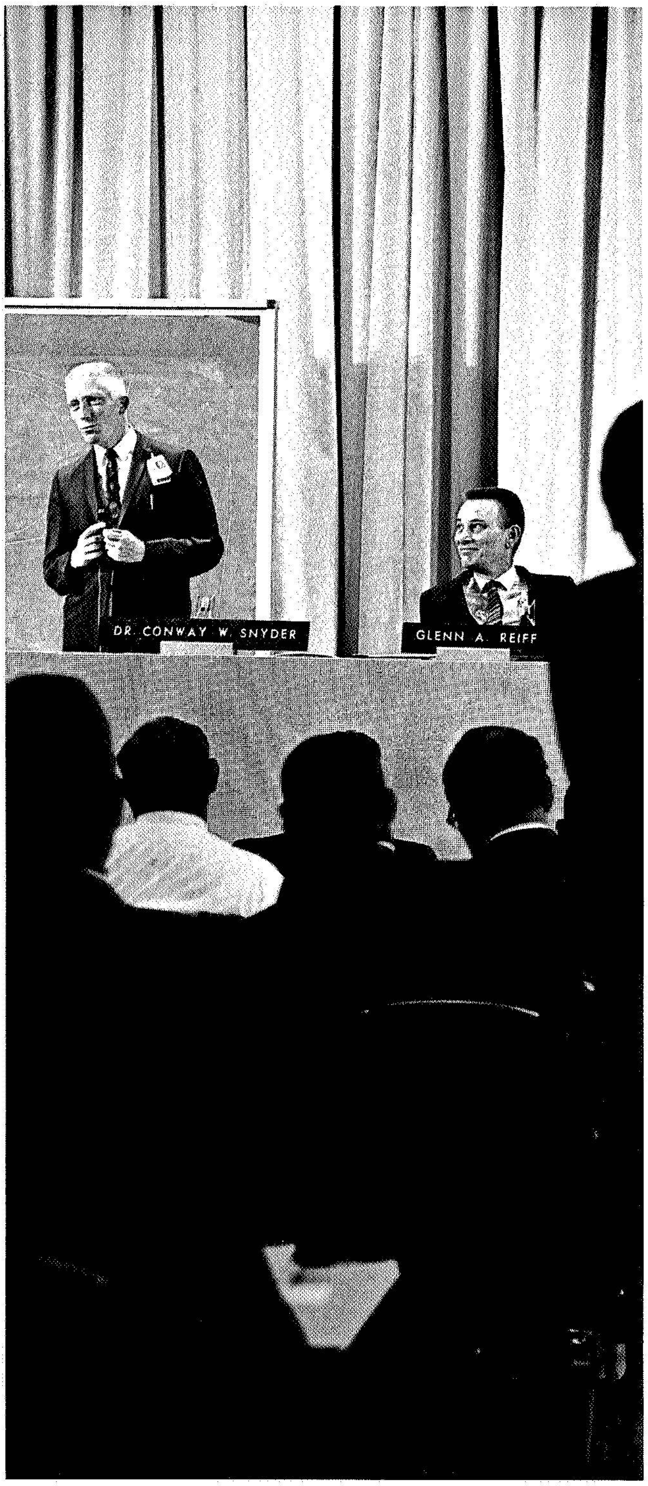
Behind the planet, the terminator sensor tracked across the night side, the twilight zone, and then the sunlit brightness of the clouds. The brightness signal triggered an explosive latch, about twelve minutes after closest approach as shown in the tape, and the elliptical reflector antenna through which Mariner sent its ten-watt signal moved away from the dark limb of Venus toward the lighted edge of the disk. It had not been pointed directly at the Earth in its original fixed position, but rather a little behind it, so as to compensate for the bending of the signal through the atmosphere of Venus. Now it must compensate in the opposite direction.

In the close brush with Venus, the planet's gravity pulled Mariner's trajectory into a tight arc of more than 100 degrees. As a result of the gravity turn, the spacecraft, which had started 94.4 million miles from the Sun, would now come in closer than 54 million miles, and would never again be more than 68.3 million miles from the Sun (Venus' orbital radius is 67.1 million miles).

Mariner V emerged from behind Venus on schedule, and the scientific data recording continued at the spacecraft and at Goldstone. About an hour after closest approach, the tape was complete, and the active encounter with the planet was effectively over.

Ten hours after closest approach, an internal command began the playback phase. Unlike the Mariner IV operation, in which twenty-two television pictures had been recorded, each expressed in a quarter of a million digital bits and requiring more than eight hours to transmit, transfer of the Venus data was relatively simple and swift. The tape-recorded scientific information was played back twice in three days, interspersed with the necessary tests and calibrations, and intervals of live engineering telemetry. With that, Mariner's return to Venus was complete; mission accomplished.

OBSERVATIONS



The planet which Mariner V left behind in its journey toward and around the Sun has been translated from a mystery into a puzzle by the scientific spacecraft visits of October 1967. It is a match for the Earth in size and mass, and our nearest neighbor among the planets, but the new information has continued the trend away from any similarity between Earth and Venus.

Precise analysis of ranging and doppler tracking of the spacecraft in its course around and past Venus found the planet to be 1/408,522.6 as massive as the Sun, with an accuracy of one part in a hundred thousand. A new, independent measure of the planet's radius, combining Earth-based radar astronomy with Mariner V celestial mechanics data proved to be possible. The occultation technique could not give a radius measurement, since the atmosphere blotted out the signal before it reached the surface.

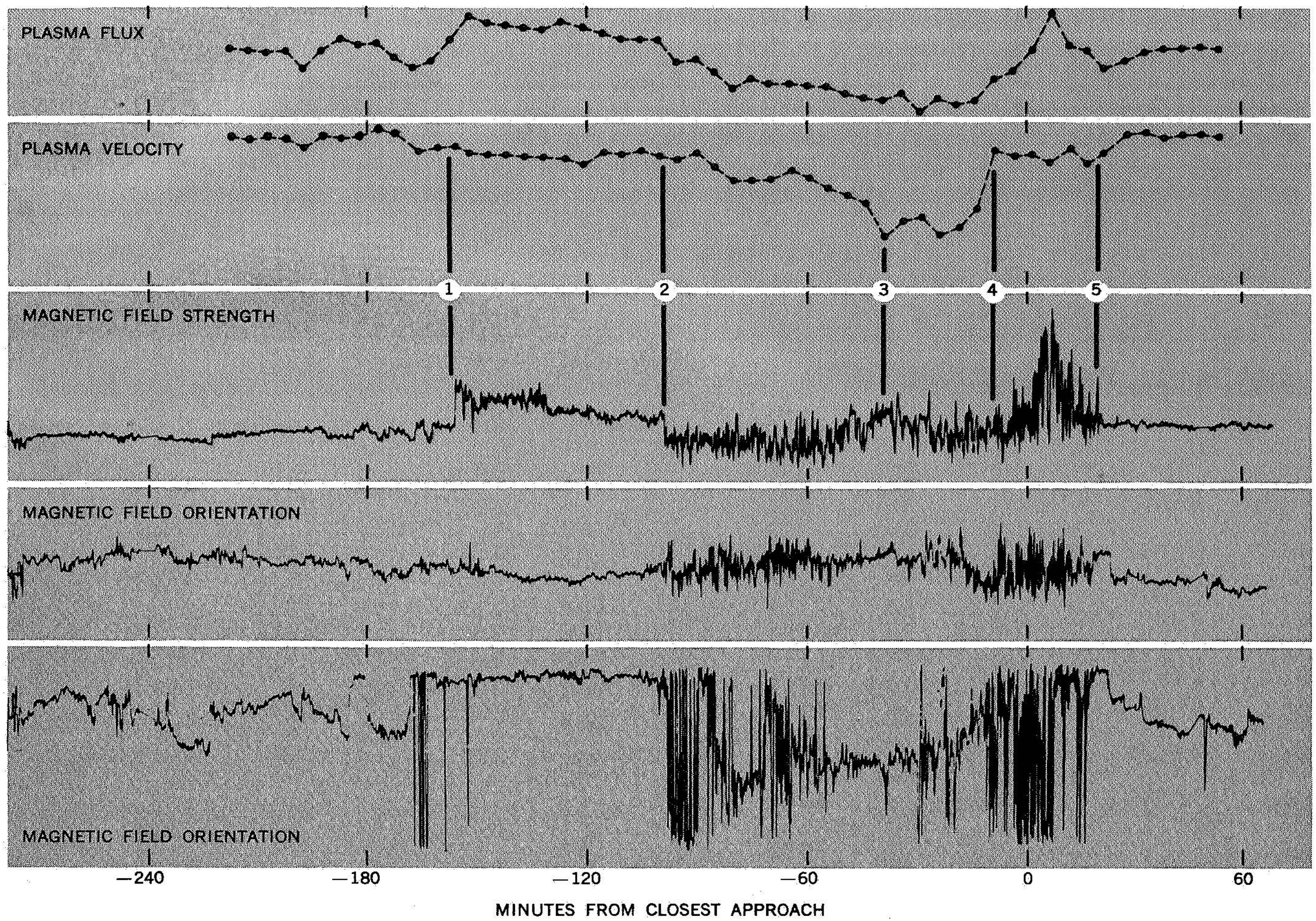
Preliminary correlation of the published final temperature and pressure readings of the Venera-4 capsule with the atmospheric profile from the Mariner S-band occultation data suggests that the Venera readings were taken at a radius of 3772 to 3784 miles from the center of Venus. If this is at the surface, it should be compared with the 3763-mile radius calculated from many radar observations.

FIELD AND SHIELD

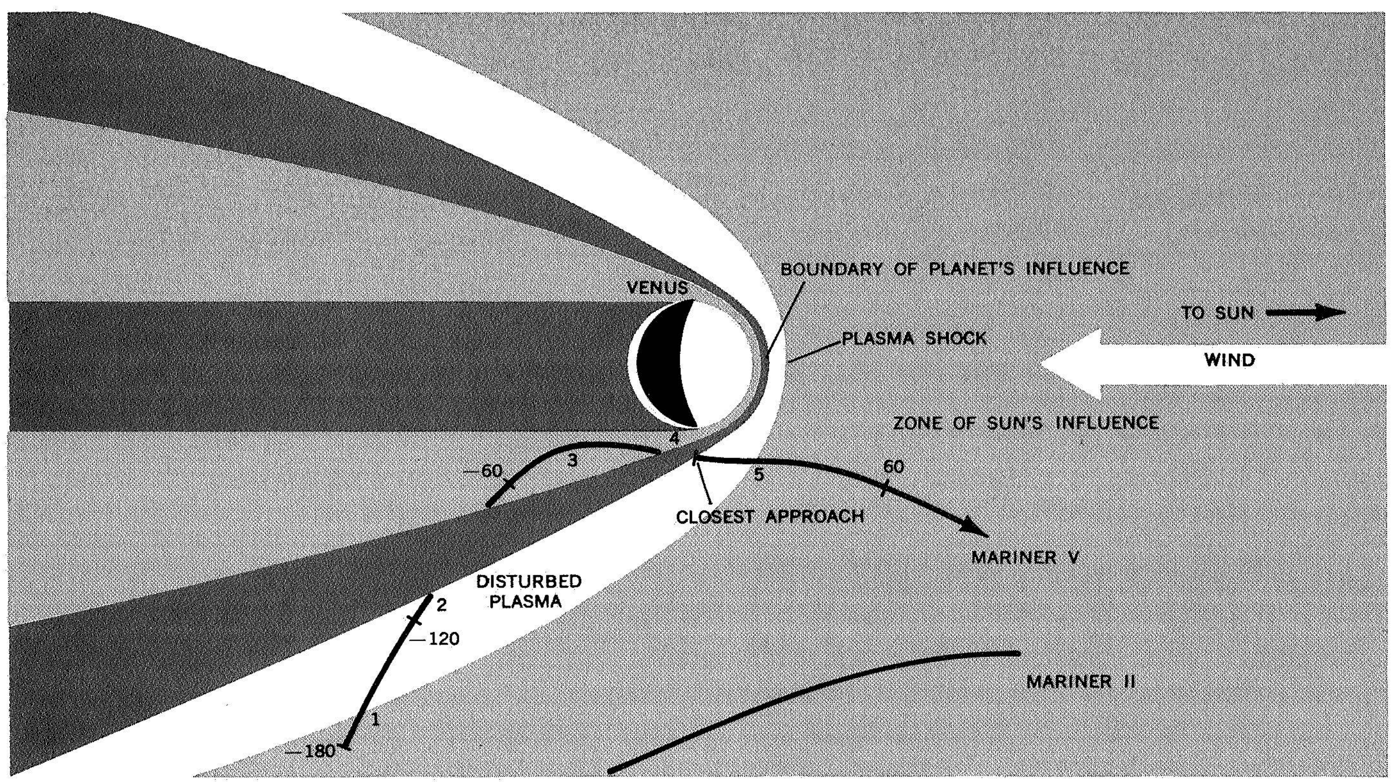
Mariner II had found that the magnetic field of Venus could not be stronger than five to ten percent that of Earth. Mariner V, flying much closer to the planet with a more sensitive instrument, reduced this maximum value to one-half to one-tenth of one percent. Actually, no spacecraft has ever measured any specific magnetic field at any planet but the Earth. It is the absence of planetary or lunar magnetism, noted at progressively closer ranges with increasingly sensitive instruments and experiments, which has been incorporated into planetary theory.

Magnetic fluctuations observed by Mariner V near Venus were combined with plasma measurements, the

First release of encounter results to press and public, by Project Scientist



Above, actual data returned on flux and velocity of solar wind (dotted curves) and strength and direction of magnetic field (lower curves), from which scientists deduced conditions around Venus, shown below. The numbers show the correlation of the two pictures. Below, the path of Mariner V is plotted to show its orientation to the Venus–Sun line, which is the axis of the plasma interaction shells.



Mariner V experimenters meet the press: Left to right, E. J. Smith (magnetometer), A. Lazarus (plasma), J. A. Van Allen (trapped radiation), C. W. Snyder (Project Scientist, plasma), A. J. Kliore (S-band occultation), V. R. Eshelman (dual-frequency), C. A. Barth (ultraviolet photometer), J. D. Anderson (celestial mechanics).

trapped-radiation detector's readings, and the ionosphere profile derived from the two radio occultation experiments to draw a striking picture of the space around Venus.

Our Earth dominates a large volume of space whose boundary has about ten times the radius of the Earth in the direction of the Sun and stretches hundreds of times as far in the opposite direction. Within this region, our magnetic field holds sway, trapping charged particles and confining them in narrow shells. Above it, there is a transition zone, topped by a shockwave interface with the solar plasma.

A weaker but similar structure was apparently detected around Venus. However, the zone of planetary influence appears to be held open only by the effect of the ionosphere. The zone is compressed close to the planet on the sunlit side by the pressure of the solar wind, and the outer shock front was only about two planetary radii out when Mariner passed through it on its way out, about 45 degrees from the sunline (about one-fifteenth the corresponding measurement for Earth). There were no detectable shells of magnetically trapped charged particles analogous to those above the Earth.

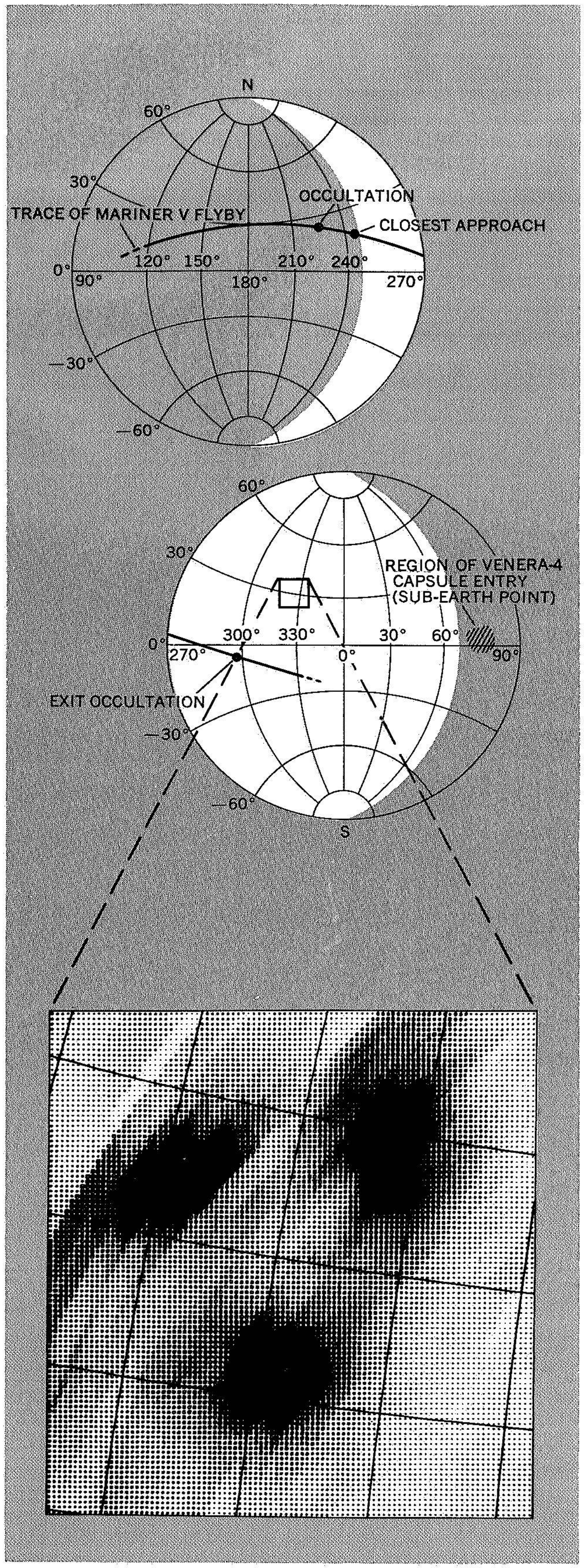
ATMOSPHERE: DEEP AND DENSE

Venus' upper atmosphere was found to be huddled close to the planet. The atomic hydrogen cloud measured by the ultraviolet photometer faded into the background about 12,000 miles above the surface, while Earth's cloud stretches five times as far. Evidently the effective temperature at this altitude above Venus is much lower than it is above Earth. In addition, the ionosphere was contained by the solar wind below an altitude of 370 miles on the day side, where Earth's ionosphere trails off a hundred times as far. However, the atmosphere is not shallow; the occultation data show that at Earth's normal sea-level pressure, Venus' surface is still 28 miles below.

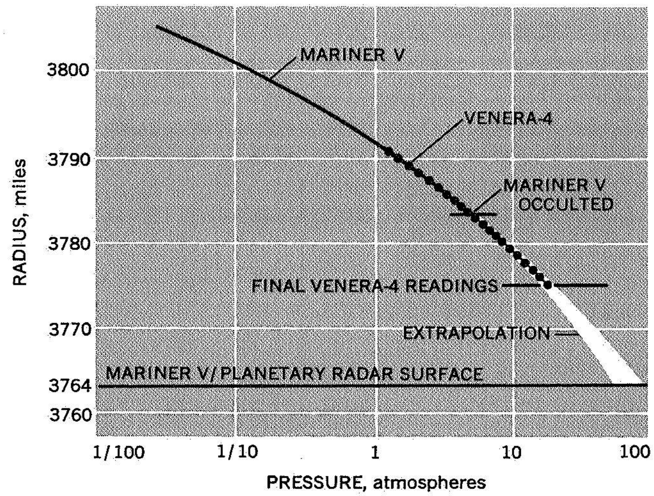
Mariner's ultraviolet photometer did not find the high-altitude atomic oxygen for which it searched. This negative observation bore out the Venera-4 measurement of very small quantities of molecular oxygen and water in the lower atmosphere. The instrument did discover a low-altitude ultraviolet glow in the night sky of Venus. This phenomenon, of unknown origin, might be associated with the visible "ashen light" observed first by Riccioli in 1643.

Mariner V did not make direct measurements of the composition, temperature, pressure, and density of the atmosphere, but rather a series of deduced profiles based on radio-signal refraction and attenuation in the atmosphere. The temperature-to-molecular weight ratio observed in the upper atmosphere (3810–3820 miles from the planet's center) was 5.5 to 5.9; the temperature was assumed to be 230°K absolute or about −45°F. Thus the average molecular weight is 39–42 (the molecular weight of carbon dioxide is 44, that of nitrogen gas 28, of molecular oxygen 32, water vapor 18). It was accordingly estimated that the carbon dioxide abundance at this level must be about 70–90 percent.

The composition reported from the Venera-4 results was between 80 and 100 percent carbon dioxide; nitrogen undetected (with a fairly insensitive detector, which may not have worked); oxygen 0.4–0.8 percent; water 0.1–0.7 percent. The large uncertainty in the carbon dioxide percentage and the failure to measure nitrogen, or the chemically inert gases such as



Above, globe of Venus shows trace of Mariner V pass, probable entry region of Venera-4 capsule, and location of one major radar-roughness feature, shown in a detailed two-dimensional plot below.



Representative preliminary interpretive correlation of Mariner V, Venera-4, and Earth-based planetary radar data into composite pressure profile.

argon, leaves any estimate of the composition somewhat open; but there is clearly a mutual confirmation between the two missions that the major part of Venus' atmosphere is carbon dioxide, as suggested by the "greenhouse" model of the early 1960s. The Soviet scientists state that the temperature at the surface is 505–530°F, and the atmospheric pressure is 16 to 20 atmospheres (one atmosphere being our normal pressure).

THE HEAT OF THE NIGHT

It is interesting to note that the region where the Venera-4 capsule descended, and where the Mariner radio beams impinged as occultation began, was on the night side, in a position corresponding to the small hours of the morning. Yet it appeared to be as hot there as it was near the subsolar point, where it was noon or early afternoon. On the Moon, which has a long night, the difference between day and night temperatures is hundreds of degrees. But on Venus, the heavy atmosphere not only prevents cooling at night, but it presumably brings heat around in warm winds. In addition, it reaches a sufficient density so that if the air were clear, the Sun would be visible at night, refracted all around the horizon. Light rays are bent around the planet in the lens-like atmosphere, just as Mariner's radio signals were bent. The bending varies with wavelength, so that the beam is spread as well as bent; thus the Sun at night would appear as a horizontal rainbow smear. Since the cloud layer in the atmosphere is opaque, there cannot be any sky displays to brighten an otherwise intolerable environment.

Thus Venus appears to offer roasting heat, a choking atmosphere, crushing pressure, and murky skies, to which forbidding weather and hostile terrain may perhaps be added. It is essentially as we have been warned for years; still in a way, it was unhappy news.

AFTER

After leaving Venus and completing its mission, Mariner V had about a month of active life before the changing orientation cut off communication with Earth for several months. Mariner IV, the original twin, engineering predecessor, and on its return from the far side of the solar system the operational companion of the Venus spacecraft, had two months left of life. One of its two attitude-control cold-gas systems had become depleted early in October; the second was nearly empty. So it was time to do what could be done: with the newer mission, to prepare for the long period without communications, and for the older one, to carry on to the end and then to stop.

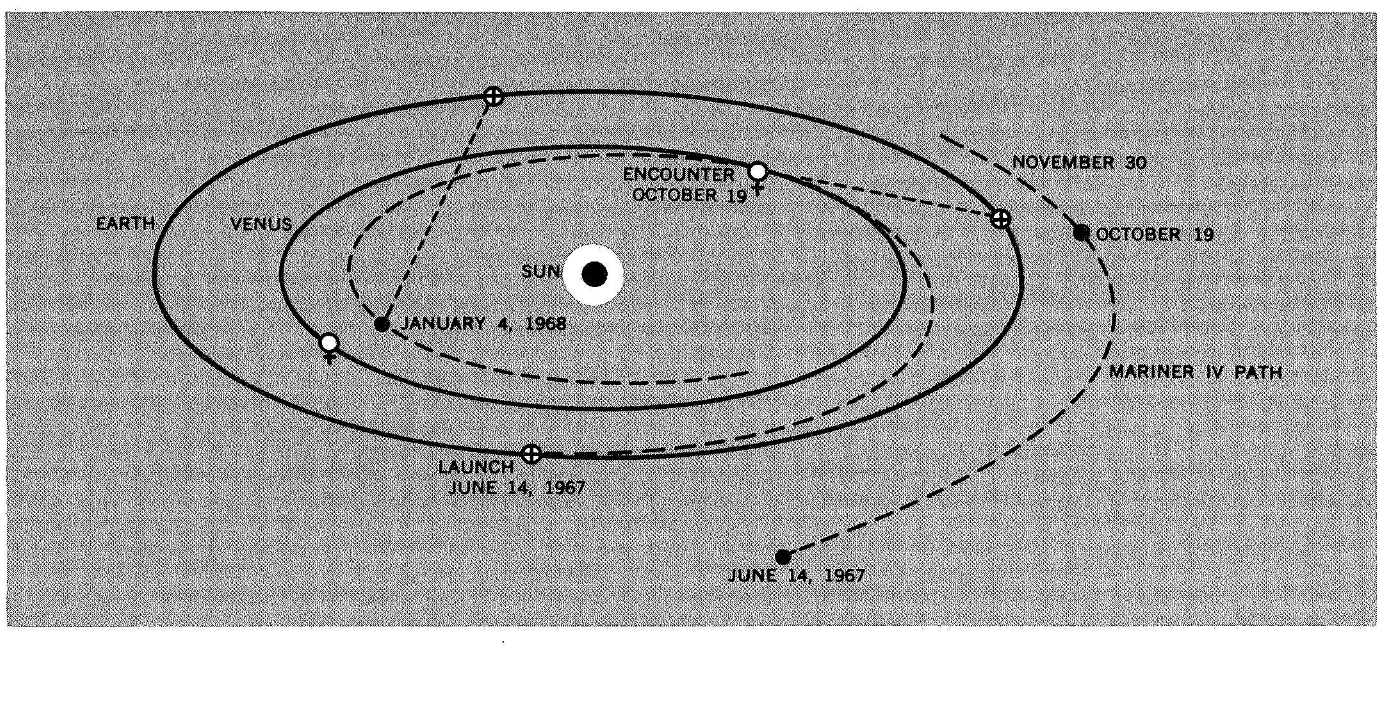
BEYOND VENUS

Mariner V continued to draw nearer the Sun, and to demonstrate each day the ability of its thermal design to survive a greater heat input in space than any spacecraft had ever withstood. It would pass closer to the Sun than any previous man-made object. By the end of the month, the solar panels had reached 250°F, and the temperature was rising faster than one degree per day, but they were expected to survive the closest approach to the Sun with a 20-degree margin. The plasma probe, facing the Sun, grew hotter than 105°F, more than anticipated, but was still expected to survive. The interior temperature of the spacecraft rose slowly through the sixties during the flight, and was not likely to see unreasonable heat.

As the spacecraft drew far from Earth, and turned away to pass around the Sun, the signal strength grew steadily less. As the engineers began to look ahead, a long life in space became a prospect for Mariner V. With an orbital period of 195 days, the spacecraft would be close to Earth (just outside Venus' orbit) about every fourteen months; communications could be established for several months each time, so long as the spacecraft was operating. The attitude-control gas system, the depletion of which would shortly retire Mariner IV after three years, was expected to last six more years (Mariner II, the first interplanetary traveler, had lasted four months). No equipment failures aboard the spacecraft had been detected.

A number of engineering operations and tests filled the month after the Venus encounter. Two notable events had to do with the ultraviolet photometer.

This instrument had observed a great circle of stars on launch day when the spacecraft was rolling to calibrate the spacecraft magnetic field. On November 7,



Mariner had traveled a half-circle around the Sun from its celestial longitude at launch, and the same ring of stars would be in view. Accordingly, it was rolled again, three times, by overriding the Canopus sensor's lock on the star with a ground command. The tape recorder was induced to record the measurements by means of a simulated encounter sequence (the only way to turn it on) prepared and initiated with the same three ground commands used near Venus. Since there was no planet in view to actuate the planet sensor, the backup Clock A in the data automation system governed the recording operations.

Ten days later, a simulated midcourse maneuver was combined with the simulated encounter to sweep the photometer (and the midcourse motor nozzle) across a different skein of stars. Firing up the motor was avoided by switching the start current to the explosive valves, which had been expended in the original course-correction maneuver in July. The spacecraft simply pitched about 17 degrees from the Sun toward Earth, rolled through seven-eighths of a full circle, and then reacquired the Sun and Canopus. The ultraviolet instrument outputs in each case were played back off the tape recorder after the maneuver for study and calibration.

THE END OF MARINER IV

Operations with Mariner IV were of a different character. This spacecraft was three years old in flight. It would soon go out of service permanently. There were a good many engineering tests which could be performed in order to add to the technology of developing long-life spacecraft, a technology very necessary to the future of interplanetary exploration, where a three- or eight-month flight to Venus or Mars is the first and shortest step.

Since Mariner IV was more than 120 degrees away from Mariner V in the sky, simultaneous operations of the two spacecraft were possible most of the time. Thus in the days before Venus encounter, several commands were sent to Mariner IV to change and test the guidance modes. After the active period with the Venus spacecraft, the older machine was rolled under gyro control until, on October 26, the telemetry rate was switched to 33⅓ bits per second (the high rate), and the signal was switched to the high-gain antenna, which was pointed approximately at the Earth for the first time in more than two years.

This improvement of the communications rate was necessary to the next test of the Mariner IV spacecraft—a thrust maneuver. Minimum turn commands were loaded into the central computer's maneuver counters, together with a long thrust period (almost 70 seconds). This would keep the antenna pointed at the Earth, and ensure a long period of study of the dynamics and other effects of the firing of the rocket motor—assuming that, after thirty-five months of cold storage, the motor would work. So, at 0415:21 GMT, which was 11:15 the previous night at Goldstone, the maneuver go-ahead was sent to Mariner IV. A long hour and fifty-four minutes later, the fifty-pound-thrust motor flared into activity for more than a minute. Through it all, the telemetry continued.

Eighteen hours later, another operational test started. After an exercise of the telemetry mode changes and of the encounter mode, with the TV camera scanning back and forth without recording pictures, the tape playback mode was commanded on, and samples of two-year-old recorded video of Mars were transmitted to Earth.

Over the next several days, repeated commands exercised the attitude-control system, changing the angle of the Canopus tracker, rolling the spacecraft in steps, turning gyros on and off. The battery charger was exercised; the alternative circuits and amplifiers in the radio were tried out. On November 22, a series of TV pictures of the space scene were recorded; a week later, the playback exercise was carried out.

The telemetry had been showing the attitude-control nitrogen-gas pressure at zero for weeks. Then, on December 6, Mariner IV breathed its last. Spinning slowly, facing the Sun, communicating with Earth, but virtually helpless, the machine ran on and ran down. A week over three years in flight, it had been to Mars and the far side of the Sun before coming back past Earth again. The roll axis, core of the slow spin which followed the last corrective burst of gas, wobbled off the Sun line until it was sweeping out a fifty-degree cone, which so interrupted communications that all operations were terminated on December 20, 1967.

AU REVOIR

Flight operations had been closed out for the Venus mission almost a month earlier. With the simple inevitability of a law of nature, Mariner V and the Earth reached the point of parting in their differing paths around the Sun. The tests were done; the spacecraft still worked flawlessly. A few simple commands prepared it for seven months alone. With the last of them, the signal from the high-gain reflector antenna died away; seven minutes and twenty seconds later, the silence reached the Earth. Should it survive, as we expect, a close passage by the Sun, this Mariner too will return to communicate with Earth.

The two Mariners of 1967, one returning from its journey, the other outward bound, both carrying our hopes to the planets and returning knowledge of new worlds and new technology, patrol the frontiers of the great adventure called space exploration. But not for long alone. For we shall look upon their kind again.

MARINER V FLIGHT LOG

June 14, 1967, 2:01:00 AM, Cape Kennedy, Florida: Liftoff
0624:36 GMT (23 min 36 sec after liftoff), about 120 miles above the Gulf of Guinea: Injection into interplanetary orbit
0643–2400 GMT: Roll for magnetometer calibration, UV sky search

June 19, 2018–2332 GMT, about 983,000 miles from Earth: Midcourse maneuver, changing velocity about 35 mph, moving aiming point 47,000 miles toward planet

July 24, 6.6 million miles from Earth: Telemetry change from 33⅓ to 8⅓ bits per second

August 19–21, about 12 million miles from Earth, 82 million miles from Sun: Approximate line-up with Sun, Earth, and Mariner IV

October 1, 35 million miles from Earth, 3.1 million miles from Venus: Communications switch-over from omnidirectional to high-gain antenna

October 19, 1734:56 GMT, 2455 miles above surface of Venus, about 50 million miles from Earth: Planetary encounter, scientific operations near planet for about 2 hours before and after closest approach; spacecraft passes Venus at 19,157 mph (see pp. 25–28)

October 20–23, receding from Venus at 7000 mph, about 51 million miles from Earth: Tape playback of planetary scientific data

November 7–8, 62 million miles from Earth, 3.2 million miles beyond Venus, 64 million miles from Sun: UV sky search repeated, halfway around Sun from launch

November 21, 73 million miles from Earth, 61 million miles from Sun: Spacecraft prepared for long-term cruise around Sun, last telemetry received

January 4, 1968, 53.9 million miles from Sun, 116 million miles from Earth: Perihelion, closest approach to Sun; maximum orbital velocity, 92,491 mph

FOR MORE INFORMATION

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